Collaborative Technology Alliances

2002 ANNUAL REPORT

Advanced Sensors

Advanced Decision Architectures

Communications and Networks

Power and Energy

Robotics

Science and Technology Innovations for the Objective Force

Contents

A Message from the ARL Director (A)

Mr. John M. Miller

ARL has established five consortia of leading industry and university researchers that plan and execute collaborative research with government partners. The focus is on the rapid transition of innovative technologies to the warfighter to enable the Army's Objective Force.

Collaboration among leading scientists and engineers in government, industry, and academia sets up great expectations for impressive results, and the Alliances are making significant progress. Examples of noteworthy highlights include:

- Breakthrough in electronically-tunable infrared detectors, enabling simpler, cheaper hyperspectral imagers for improved detection of camouflaged and low-observable targets (Advanced Sensors Alliance).
- Fabrication improvements in the areas of high temperature materials and 3-dimensional structures for Power Micro Electro Mechanical Systems to enable the microturbine to reach its 5- to 10-fold increase in power density projections (Power & Energy Alliance).
- Technology breakthrough achieved in the ability of intelligent unmanned ground vehicles to perceive and autonomously navigate complex, unstructured terrain with minimal human supervision. Technology transitioning to multiple high impact applications including FCS Armed Robotic Vehicle, OFW Mule, and as physical security element of Force Protection (Robotics Alliance).
- Protocols for automatic configuration of routing, security, and quality-of-service that enables more rapidly deployable mobile networks (Communications & Networks Alliance).
- Decision making tools that improve collaborative situation awareness and reduce soldier workload, improving soldier survivability (Advanced Decision Architectures).

Another key indicator of success is that in 2002, $20M from other agencies was placed on the Alliance transition contracts to leverage our $34M core research program and rapidly transition research products to Army applications. Other quality indicators include:

- Support for over 250 graduate students, with completion of 19 PhD degrees and 7 Master's degrees, and sponsorship of 60 Post Doctoral Fellows.
- 90 technical staff rotations into ARL from academia and industry, and 20 researchers out of ARL to partners' facilities.
- Over 200 refereed papers and proceedings published.
- 28 workshops, seminars, and short courses on the latest Alliance technologies.

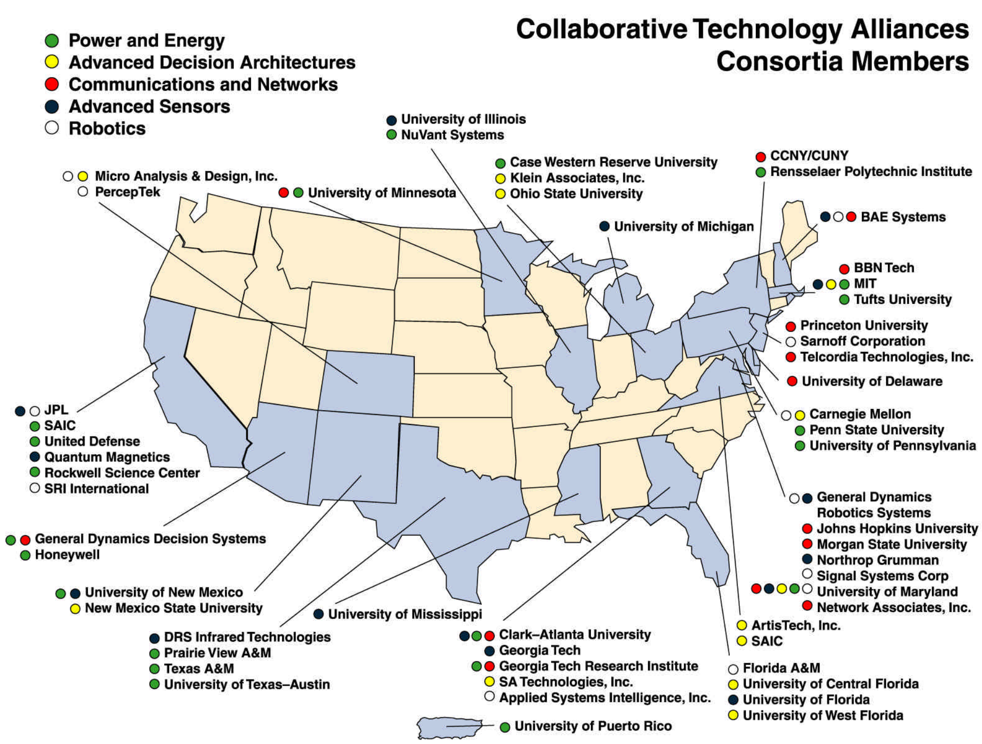
We at ARL are proud of these and many other accomplishments described in this report. We expect continued significant impact on science and technology innovations for the Objective Force as we move forward.

Overview of the Collaborative Technology Alliances

The Army's Collaborative Technology Alliance (CTA) program was formed in 2001 to establish partnerships among research communities in the Army Laboratories and Centers, private industry and academia. Each alliance member brings with it a distinctly different approach to research: Academia is known for its cutting-edge innovation; the Army Research Laboratory (ARL) researchers keep the program oriented toward solving complex Army technology problems; the industrial partners leverage existing research results for transition and deal with technology bottlenecks. The CTA concept capitalizes on the innovative academic research ideas coming from the university partners. These ideas are then augmented by the strong applied research capabilities of the commercial sector and the focused research products of the Army Research Laboratory. The three sectors collaborating together as one team provide the means for innovation and rapid technology transition. These multidisciplinary research teams generate the complex technology needed to solve the Army's complex problems. This approach enables the CTA program to bring together world class research and development talent and focus it on Army-specific technology objectives for application to Army Transformation.

Under the CTA program, Cooperative Agreements were awarded to five consortia in the following technical areas: Advanced Sensors, Communications and Networks, Power and Energy, Advanced Decision Architectures, and Robotics.

Each Consortium is comprised of leading academic and industrial partners. The map below shows the members of all five consortia and their locations. While all five consortia are managed and operated separately, they have a common set of management and program characteristics.



CTA member organizations.

A Consortium Management Committee (CMC) manages and governs the Consortium. The CMC decides all policy, business, financial, and technical issues of the Consortium, and represents the Consortium in reporting progress and transacting business with ARL. The CMC is responsible for the management and integration of the Consortium's efforts. The CMC determines the membership of the Consortium. It defines the tasks and goals of the partners and determines the distribution of Agency funding to the partners. The CMC provides for ex officio representation by the Collaborative alliance Managers (CAM) and other government personnel from other government agencies (OGA).

The CMC consists of leading individuals from member organizations. Each member organization has one voting representative on the CMC to support programmatic and management-related activities and decisions. The CMC meets quarterly. The consortium's research is organized into technical areas, each of which is led by an expert from an industrial member with an established presence in that technology. To ensure that there is a close working relationship between the consortium and the Army, ARL assigns a member of its staff to serve as a counterpart to each technical factor leader.

The Alliances in the CTA program include not only the five consortia and ARL, but also Army Research, Development and Engineering Centers (RDECs), other Army and other Government agencies (OGAs). The Army RDECs and OGAs are invited to actively participate in the research program and to conduct research jointly with Alliance members. The annual research program plan is also cooperatively formulated by Alliance members and ARL with input from the RDECs and OGAs, through participation on the Research Management Boards (RMBs) established for each Alliance. The RMB partners are critical to identifying opportunities for transitioning CTA research results into their on going R&D programs. This transition is facilitated by a task order contract built into the CTA agreements. Several Army RDECs and OGAs took advantage of this contract mechanism in 2001 to apply CTA research results to their technology development programs.

The CTA program's value to the warfighter is significantly enhanced when we exploit the full potential of the enabling technologies that result from the basic research projects. Our technology transition approach relies on collaboration and partnering of ARL, RDECs and RMB members. This team works with the technology user community to seek out transition opportunities and to demonstrate technologies mature enough for application. Our approach extends activities beyond research papers to matching technology with customers early and then jointly mapping the transition path with them. The identification of user champions through early and frequent collaborations and partnerships is a key component of our process for effective transition with defined entrance and exit criteria.

CTA researchers participate in many key defense programs such as Future Combat Systems (FCS), Objective Force Warrior (OFW), DARPA Total Information Awareness and Warfighter Information Network—Tactical (WIN-T), and Adaptive Joint CISR Node (AJCN). Furthermore, each CTA member provides world-class laboratory facilities and testbeds for use by ARL and other CTA members. These facilities create tremendous leverage for the Army science and technology program.

Today's complex technology challenges have made it absolutely necessary to engage researchers on these multidisciplinary teams, where new ideas can be successfully applied to complex Army problems. This is the Army's way of establishing a new research culture—transforming the old way of doing business—that fosters a different kind of relationship among research colleagues in industry, academia and Army laboratories and centers. As an integral part of the program, the CTAs use several venues through which such synergistic collaborations can be pursued and encouraged. Some of the venues used by the CTA program are summarized below:

- **Joint Research Projects:** The individual researchers collaborating on a particular research topic are involved in the planning at the task level as well as in the execution of the overall research project. On many projects the researchers come from each of the three sectors—academia, Government and private industry—bringing the advantages of a multidisciplinary approach to the research problem.
- **Staff Rotations:** The best example of collaboration is staff rotation, in which individuals temporarily relocate, if necessary, to work on a daily basis with the research group at a partner's organization. Such rotations may last months or years. The rotations produce mutual understanding of technical approaches and issues. The sharing of expertise among the participants fosters new insights into difficult research problems and creates opportunities for advances not previously recognized before the exchange of personnel. In some cases the rotation is combined with a long-term training/educational component. This provides educational opportunities for graduate students from academia and staff scientists and engineers from government and industry to earn advanced degrees and to perform cutting-edge research. The collective result is enduring individual and institutional associations whose growth far exceeds the separate capabilities.
- **Workshops:** Each technical area conducts focused workshops to discuss technical progress and challenges unique to that topic. This provides a forum for effective interaction between researchers from ARL, the participating consortium members, and Army RDECs.
- **Distinguished Lecture Series:** Experts from consortium partners and ARL present monthly seminars to more broadly communicate the technical issues and progress on specific projects. Members of all CTA alliances are invited to attend either in person or via video teleconference.
- **Seminars and Short Courses:** More informal seminars and short courses are conducted frequently and primarily involve members of a particular CTA or technical area. Certain seminars are specifically designed to address technical areas which include several CTAs and serve as starting points for cross-CTA collaborations. Short courses are developed for particular projects that cross multiple disciplines. In these cases, it is of particular benefit for researchers to gain more in-depth knowledge of all technical areas within the project; an expert presents technical material specifically designed for the purpose.
- **Annual Symposium:** The CTA program holds a symposium each spring to present the results of its research and to describe plans for the next year. Program overviews, technical papers and posters, exhibits and demonstrations serve to communicate the research products of the CTA program to Army organizations and other agencies. The symposium fosters interactions and collaborations among researchers from all the technical areas and all the alliances.

A cornerstone concept of the CTA program has researchers sharing ideas and research findings, while working in a common environment, to accelerate the development of new technology and provide a rapid transition path into applications. Full details of technology transitions will be provided in this report's sections on CTA highlights. Some of the flagship transitions are highlighted below:

- The Advanced Decision Architectures (ADA) CTA is developing threat Visualization and Decision Aid Tools for presentation into the current Information Dominance Center (IDC) architecture.
- In the *Advanced Sensors* CTA (ASCTA), BAE Systems is developing a low Power Modular Acoustic and Imaging Sensor (MAIS) compatible with the common architecture for micro sensor prototypes.
- In the *Communications & Networks* (C&N) CTA, the University of Maryland is developing a specialized network of sensors (SNS) capable of real-time precise characterization of free-space optical communications channels.
- The *Power & Energy* (P&E) CTA conducted a task for the Natick Soldier Center to examine designs of methanol-based fuel-cell systems for a soldier application.
- The *Robotics* CTA is finalizing development and demonstration of a team of cooperating mobile robots that reduces the risk to Explosive Ordnance Disposal (EOD) personnel during war-time clearance of multiple unexploded submunitions on the surface.

From the cooperative program formulation through the collaborative research efforts, the CTA program is efficiently focusing the expertise of industry, academia and the Army Research Laboratory on enabling technologies and new military capabilities needed for Army Transformation.

A Message from the Advanced Decision Architectures (ADA) Leads

Dr. Michael Strub (ARL)

Collaborative Alliance Manager

911 was our wakeup call ushering us into the new era of asymmetric warfare in which our enemies seek to exploit our vulnerabilities and achieve disproportionate effects. The Advanced Decision Architectures Alliance supports the Army's transformation to the Objective Force by defining the key cognitive parameters and developing models, displays, and architectures to support the distributed, collaborative decision processes envisioned for use by the Army in the first half of the 21st century.

Ms. Susan Archer (Micro Analysis & Design, Inc.)

Consortium Program Manager

The research vision of our alliance is "To work together to develop, test, and transition new user-interface technologies and design practices and principles that will facilitate better soldier understanding of the tactical situation, more thorough evaluation of courses of action, and, ultimately, better and more timely decisions."

Advanced Decision Architectures Research Focus

To achieve our research vision, the CTA ADA research focuses on four main technical areas, with cross-collaboration between areas:

- ***Cognitive Process Modeling and Measurement***: This technical area involves a variety of related topics. Cognitive processes are being modeled as a foundation for collaborative technologies and decision support systems. Unobtrusive ways to quantitatively assess users' states are being researched to better support decision-making. Researchers are defining and showcasing user-centered design methods. Issues about trust, especially in relation to technology, are being explored and modeled to better understand the impact on performance.
- ***Analytical Tools for Collaborative Planning and Execution****:* The goal of this area is to create tools and intelligent systems that support collaborative decision making across distributed teams. This allows decision-makers to share data in meaningful ways, and to examine the impact of their decisions. This is being accomplished with two complementary approaches. In one approach, researchers are working to understand how individuals and teams make decisions, assess situations, and interact with technology. In the other approach, researchers are prototyping and iteratively testing and validating collaborative software-based tools with actual Army decision-makers. Researchers are defining the characteristics of successful tools for collaborative decision-making and are developing algorithms to support Army planning systems.

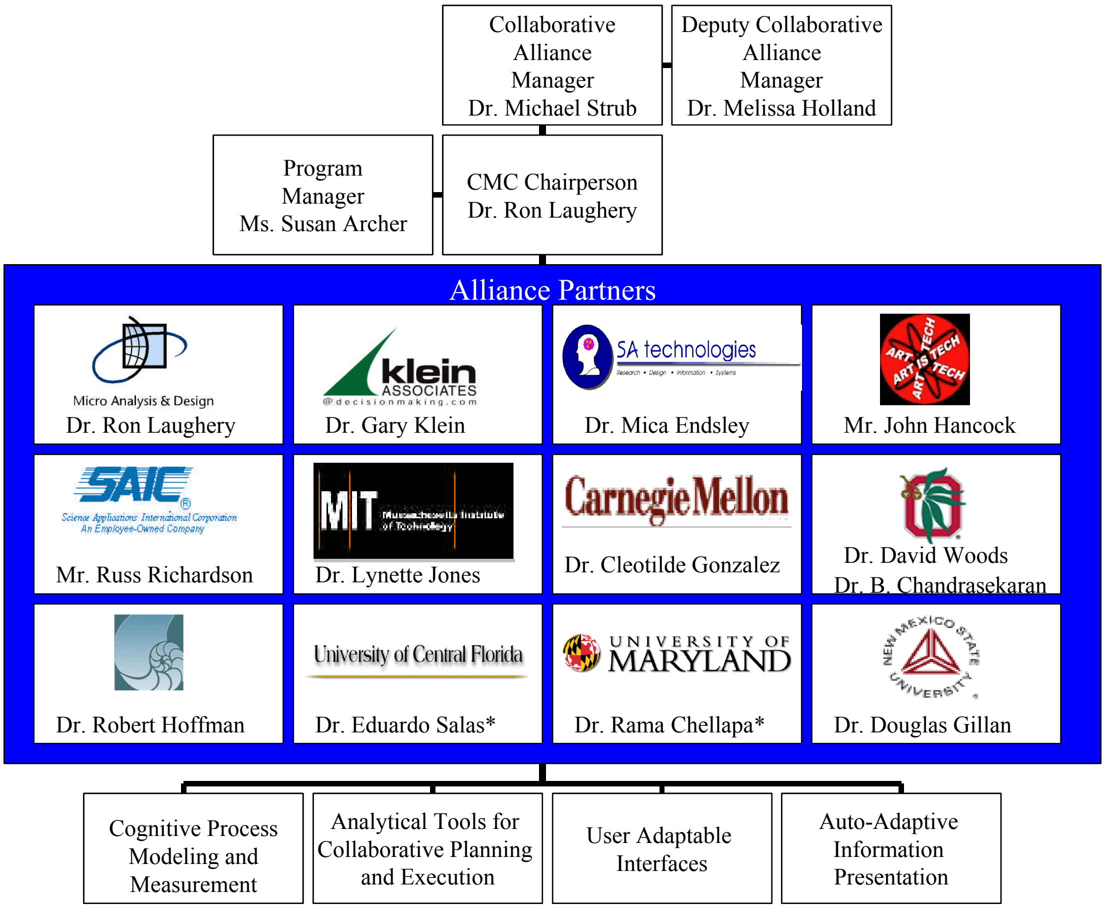
- ***User Adaptable Interfaces***: Ever since humans began using tools, we have intuitively recognized the value of adapting the interface between the tool and the human. The need for adaptive interfaces comes from differences in individual soldiers, the soldier's tasks, and the system. The goal of this technical area is to extend this long tradition of user adaptable interfaces into the world of decision-making architectures. This is being done by researching questions about interface adaptation. Within this topic we address several specific topics including image stabilization, mobile agent technology, and multi-modal interfaces.
- ***Auto-Adaptive Information Presentation***: Going one step further down the path of interface adaptation is the ability of the user interface itself to automatically adapt to the changing needs of the user. While there are risks in terms of software agents acting without the user initiation, tasks may be performed at various levels of automation depending on many factors. The goal of this research area is to build from the research conducted in the other tasks and develop a strategy and technologies to better evaluate how auto-adaptive information presentation can support tactical decision-making. Approaches to auto-adaptive interfaces seek to filter information or automatically reconfigure the user's displays to deal with problems. To determine how to best implement an auto-adaptation and information filtering schemes, the Alliance has taken several potential pitfalls into account: the need for rapid goal switching, the need for projection, and support of individual differences. Research is being conducted to develop key principles and control algorithms for applying auto-adaptation such as keeping users informed of the "big picture," keeping users in the control loop, maintaining critical cues, and using auto-adaptation only when needed.

Advanced Decision Architectures Consortium Members

The members of the consortium are shown in the following table.

Industry Partners: **Micro Analysis & Design**—develops tools for modeling human processes and cognition and conducts human-system integration of commercial and military systems. **Klein Associates**—develops and applies the concepts of Naturalistic Decision Making in time stressed, information constrained environments. **SA Technologies**—specializes in the analysis and modeling of situation awareness and decision making and the creation of SA-oriented designs for complex applications. **ArtisTech**—researches and develops advanced algorithms, methodologies, and technologies in well-conceived computer architectures to solve difficult problems. **SAIC**—leads the effort to transition technology to the warfighter and ensures CTA efforts are relevant to the Army.
Academic Partners: **Ohio State University**—is an international leader in Cognitive Engineering and Computer Science conducting field research to study cognitive systems of people and machines. **Massachusetts Institutes of Technology**—is world-renowned in computer science and information technology, artificial intelligence (AI), haptic interfaces, and human performance. **Carnegie Mellon University**—has an unusual mix of the essential disciplines to study learning and human cognition in relationship to technology. **University of West Florida**—researches cognition in humans and machines with emphasis on building cognitive prostheses to leverage and amplify human intellectual capacities. **New Mexico State University**—a minority institution, researches human-computer interaction, information visualization and retrieval, cognitive modeling, teams, instructional technology, and natural language processing. **University of Central Florida (Associate Partner)**—is heavily involved in research of decision-making in distributed and complex environments, human performance measurement, and human cognition. **University of Maryland (Associate Partner)**—is renowned in many areas including computer science and display technology.

Advanced Decision Architectures Organization



Associate (non-voting) partners

The consortium's research is organized into four technical areas, each of which is led by an expert from an industry or university member that has an established expertise in that technology. To ensure that there is a close working relationship between the consortium and the Army, ARL assigns two laboratory researchers to each technical area to serve as counterparts to each technical area leader.

Advanced Decision Architectures Research Highlights

Technical Area 1: Cognitive Process Modeling and Measurement

Macro-cognition

Macro-cognition addresses a new level of analysis among the researchers in the CTA. ADA seeks to further cognitive engineering in complex domains of practice such as Command and Control. Klein Associates is pursuing a large field study in collaboration with the Battle Command Battle Lab-Fort Leavenworth to understand macro-cognition at the Objective Force unit of action level.

Knowledge Environment

Researchers at OSU LAIR and ARL researchers have developed a framework for a knowledge environment for assisting Army decision-makers. The framework makes use of the decompositional structure of the task to identify knowledge and information sources, strategies for combining information in a task-specific way, and a task context-dependent navigable display. This framework will be used as the foundation for the knowledge environment implemented in a newly established Science and Technology Objective (STO) project on Fusion Based Knowledge for the Objective Force.

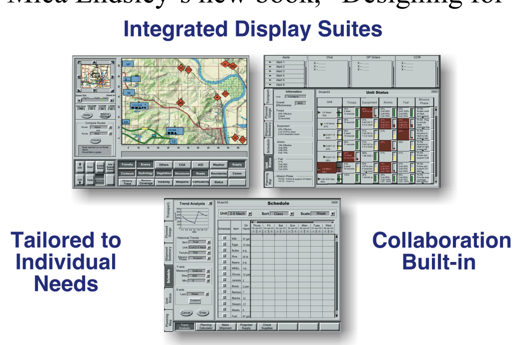
Laws that Govern Cognitive Work

OSU CSEL has integrated research results on distributed teams of people and machines into a set of Laws that Govern Cognitive Work, a high level guide for the design of cognitive work including the relationship of human and computer roles. The product is available in several forms at: http://csel.eng.ohio-state.edu/laws. They also developed a resource set on Cognitive Task Analysis—How to Study Cognitive Work in Context—in a new type of multi-media format–a Topic Landscape–available at: http://csel.eng.ohio-state.edu/woodscta.

Example of Design Influence.

Situation Awareness

SA Technologies developed a methodology and generated fifty design principles for overcoming data overload and creating situation awareness oriented designs. Dr. Mica Endsley's new book, "Designing for Situation Awareness: An Approach to User Centered Design" details this methodology and describes each of the design principles. This effort also resulted in prototype designs for a set of user-centered tools for supporting situation awareness in distributed unit of action teams. Finally, SA Technologies completed a cognitive task analyses for brigade-level command and control positions, including operations officer, intelligence officer, logistics officer, fire support officer and engineering.



Integrated Display Suites.

Computational Modeling

Several team members at MA&D, CMU, and ARL have developed new modeling frameworks to assist in predicting total system performance, where a dominant aspect of the equation is the ability of the soldier to make effective and timely decisions. This work has focused on the interaction of soldiers with unmanned vehicles.

Guidance for the Alliance Effort on Cognitive Systems Engineering

UWF has provided a summary and integration of a variety of literatures including those from cognitive science, ethnomethodology, work analysis, "high-end" human factors, sociology of scientific knowledge, and other disciplines. Ideas of user-centered design, human-centered computing, and other paradigmatic views have been summarized and integrated. Products describe a variety of methods of cognitive task analysis and cognitive work analysis.

Technical Area 2: Analytical Tools for Collaborative Planning and Execution

Team Adaptability

UCF developed a preliminary model of team adaptability and its use to develop high-level design guidelines for technologies and tools envisioned to support the Army's Objective Force. This also resulted in design and training guidelines to facilitate team adaptability.

Team Communication

Researchers at NMSU conducted an experimental study of the effect of ethnic groups, gender, locus of control and collectivism/individualism. The results can be used to develop and understand collaboration among team members. Additionally, they used latent semantic networks for the evaluation of team communication, filtering of content, and assessment of open-ended responses during training.

Team Situation Awareness

SA Technologies conducted an analysis of shared situational awareness (SA) requirements between several brigade positions, based on cognitive task analyses completed for these positions. A collaboration taxonomy matrix was created, providing an analysis of collaboration techniques and their ability to support known Army processes. SA Technologies also developed a methodology for objectively measuring shared situation awareness in military operations.

Computational Tools to Support Battle Planning and Representation

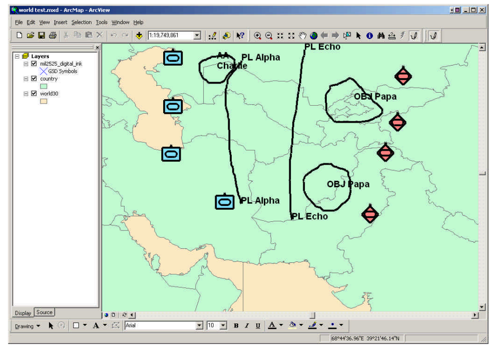
ArtisTech developed an extension to the ARL Genetic Algorithm Co-Evolution research planner which incorporated Factions and significantly expanded battle and board representation. Additionally, they furthered their work on Planneal, an approach to battlefield/plan-space representation, and an associated set of algorithms which implement a flexible, multi-dimensional route planning capability inspired by the theory of simulated annealing.

Information Communication and Fusion Approaches

OSU CSEL developed a prototype asynchronous communication tool to enhance communication of operations orders, fragmentary orders, etc. They have also developed design concepts for tools to support synchronous and asynchronous communication in continuous distributed planning in the military. Another development was an efficient algorithm for finding relatively dense or isolated groups based on message traffic. Finally, they recast "entity reidentification" into the broader context of "model-based information fusion" (MBIF) and developed a general architecture for MBIF based on a tight integration of abduction (best-explanation reasoning) with modeling and simulation.

Technical Area 3: User Adaptable Interfaces

Diagrammatic Reasoning



Application of Diagrammatic Reasoning Algorithms.

Researchers at OSU LAIR, ARL and ArtisTech developed an architectural framework for combining information from a diagram with other forms of knowledge for diagrammatic reasoning. The framework includes a family of basic perceptual routines to identify emergent diagrammatic objects and relations. They implemented the first version of the architecture for reasoning about maneuvers. They also developed Digital Ink for drawing diagrams as overlays on terrain maps and a set of visualization tools for planning information that can be overlaid on the map display.

Speech Interfaces

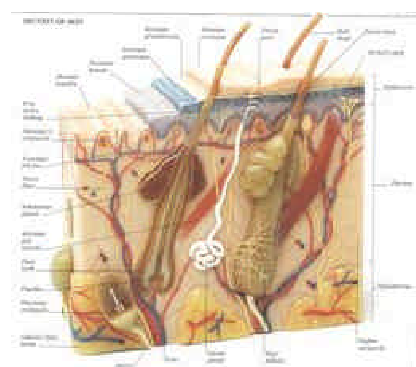
CMU researchers have built a dialogue management system, Ariadne, which handles imprecise queries and integrates alternate modalities such as speech and gesture. Ariadne supports any SAPI compliant recognizer, uses *dialogue packages* to enable novice users to create functional prototypes in 8 to 12 hours, and supports grammars that can be reused with little or no modifications.

DEM-Video Fusion

UMD has developed a method to fuse an aerial DEM (digital elevation model) with unconstrained ground video. This system is ideal for autonomous mobile robots, incorporates heterogeneous sensors and viewpoints, and provides improved situational awareness for the operator. Using the technology, the operator can move through a visual space and can view the scene from different perspectives.

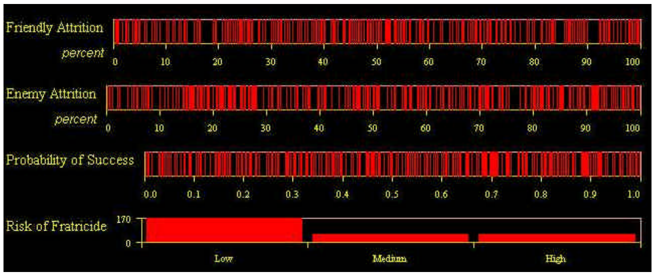
Multi-modal Displays

The human skin is an extensive sensory surface (1.8 m2), with six different types of sensors available. Certain types of information are best represented haptically, since it does not require visual attention to interpret information. In response to this opportunity, MIT researchers have built a Peltier-based thermal display for testing human responses, and an experimental test bed for tactors. Additionally, researchers at MA&D and ARL have begun a series of experiments to assess the ability of soldiers to interact with information displayed in nontraditional methods and modes. Results will be used to develop interfaces to enable decision makers to react quickly and accurately.



Receptor Surface.

Visualizing COA Trade-offs and Understanding COA Decision Space



COA Visualization Interface

OSU LAIR implemented a Java-based viewer for interactively viewing trade offs between decision alternatives on different dimensions, including decision specifications and performance criteria. In collaboration with researchers from ARL, team members developed the specifications for demonstrating this work for a problem involving course of action (COA) generation and selection in the domain of asymmetric warfare and developed a framework for using the technology to understand the relations between intermediate events in a simulation of COA and final outcomes of interest.

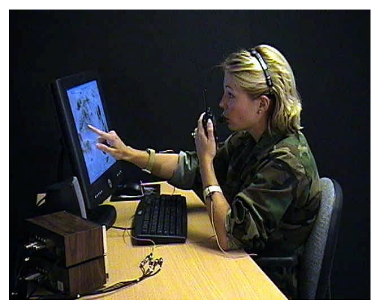
Technical Area 4: Auto-Adaptive Information Presentation

Adapting on the Move

UWF developed the first version of FlexFeed—a framework for flexible data feeds in sensor grids to support sensor tasking by soldiers in Future Combat Systems (FCS) Mobile agents are dynamically dispatched, establish the data flows and transformations in the network, and act as policy enforcers in sensor networks with a dynamic topology as nodes join and leave. Mobile code provides the means to dynamically deploy capabilities to any participating host and strong mobility allows process migration between nodes to ensure feed survivability and load balancing.

Multimodal, Multi-agent Coordination

OSU CSEL developed a medium-fidelity computer-based simulation platform to study and design multimodal, multi-agent coordination in the context of modern battlefield operations. This platform supports three communication channels—vision, hearing, and touch. It supports both human-computer interaction and computer-supported cooperative work functions in actual battlefield operations, and it supports two-way interaction with a system/person. Studies using this platform examine recovery from breakdown in multimodal interaction and uncover patterns of modality usage across tasks.



Computer-based Simulation Platform.

Minimizing Decision Making Errors

UWF used cognitive theory, specifically reductive biases, to create a database of factors that make command and control (C2) cognitively difficult. Also, UCF identified patterns of behavior that lead to decision errors under stress by analyzing historical examples and applied these fundamentals to the current military concerns for asymmetric warfare and to needs for adaptive interfaces.

Recognizing and Communicating Events

UWF created a basic temporal reasoning framework for representing time and change in formal reasoning systems. The new method allows different reasoning systems that use different representations of spatiotemporal information to "talk" to one another. OSU CSEL developed ViewTracks—a new concept for using computer 3D capabilities as mechanisms for control of point of view. ViewTracks solves the dilemma of choosing between 2D and 3D representations by integrating multiple 2D and 3D views on a scene.

Shared Displays

ArtisTech and ARL have created a framework for sharing data from the same situation across multiple display devices of varying display capabilities (including robots) that can be implemented with either a client/server architecture or an agent architecture. A prototype is being developed based upon an existing ARL Client/Server and visualization technology utilizing modern component technologies.

Advanced Decision Architectures Technology Transitions

Current technology transition activities are summarized below:

- ***Threat Visualization and Decision Aid Tools***: The research objective was to develop an information presentation test-bed and to transition relevant visualization and decision aids. Subtasks include developing an architecture for incorporating near real-time decision aids for presentation into the current information dominance center (IDC) architecture, and to develop and incorporate prototype applications. The INSCOM IDC is the Army's Tactical Operations Center (TOC) for counter terrorism, counter intelligence, counter narcotic and computer network operations.
- ***Preparing Support Package for Prototype***: The research objective was to provide associated software and facility tools to support the newly expanded IDC architecture. The results of this work enable the customer to more successfully and efficiently exploit their software tools and decision aids.
- ***Advanced Threat Visualization and Decision Aid Tools***: The research objective was to develop and augment an information presentation test-bed and transition relevant visualization and decision aids. Specifically, this work provides enhancements to the query and visualization applications, provides evidence extraction tools, links discovery models and improves the alerting capabilities of the baseline software set.
- ***Developing Adaptive Leaders and Teams for Stability and Support Operations (SASO) and Exploring the Impact of Culture Differences on Multinational Operations***: The research objective was to implement and validate decision aids to develop a framework that assists researchers in identifying and reducing the cognitive and social barriers to multi-national teamwork. This ongoing effort supports battle command for the Objective Force.

- ***A Cognitive Framework of Multi-national Team Performance***: The research objective was to establish a framework and guidance for improving the formation and operations of multi-national teams. This effort will provide a method to assess the likelihood that a proposed new team member will add value to team performance, if integrated into a multi-national organization.
- ***Decision Aids for Counter-Terrorism, Counter-Intelligence, Counter-Narcotics and Computer Network Operations***: The research objective was to provide advanced visualization display systems within the IDC to be used by analysts and commanders to quickly understand a dynamic intelligence situation and to act decisively.
- ***Modeling Human Roles in Future Navy Command and Control Systems***: The research objective was to support the Navy Strategic Studies Group (SSG) XXI in the development of methods and models to support the evolution of the human's role in future Navy command and control systems.
- ***Enhancement of Multilingual Speech Systems for Coalition Communications***: The research objective was to refine and enhance the capabilities of Speaking Minds (S-MINDS), a system originated by the Counter-Intelligence Agency. The new capabilities will support "1 and ½ way" speech translation capability for Japanese for PACOM.
- ***Improving Geocoordinate Tagging in Free Text***: The research objective was to improve the state of the art in the identification of positional information in free text, and then to mark up these items with XML encoded geocoordinates and confidence values. The resulting software will be deployed at the National Ground Intelligence Center (NGIC).
- ***Transition of Decision Aids to the IDC and mini-IDC's***: The research objective was to deploy and evaluate emerging techniques presently under development with the U.S. tech base and research community to the virtual IDC. The technology will be deployed to operational units (military intelligence) in the field preparing for contingency missions in support of national objectives.

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A Message from the Advanced Sensors Leads

Dr. Dan Beekman (ARL)

Collaborative Alliance Manager

The CTA goal of innovative joint research is impressively demonstrated by members of the Advanced Sensors CTA team, with university and industrial scientists dynamically collaborating with their ARL colleagues. The basic research program has already generated many technology transfer projects that will provide specific deliverables of interest to Army customers, and on-going research promises further advances that will result in additional capabilities for Army warfighters.

Mr. Stephen M. Scalera (BAE SYSTEMS)

Consortium Program Manager

The Advanced Sensors Collaborative Technology Alliance (ASCTA) is a consortium of university and industrial laboratories that have come together to work with the Army Research Laboratory to drive technology towards the Army's vision for transformation into the future Objective Force. Our Advanced Sensors CTA program is focused on enabling "strategic dominance across the entire spectrum of operations" through technologies that provide: (1) unprecedented battlefield situational awareness and understanding; (2) accurate, all-weather, long-range identification and targeting for beyond line of sight engagement; and (3) a multifunction RF capability for active RF sensing, countermeasures, and high-bandwidth secure point-to-point communications.

Advanced Sensors Research Focus

In order to achieve our research vision, the CTA advanced sensors research focuses on three technical areas:

- ***Microsensors, easily deployed and versatile***: Multi-modal microsensors will provide future warfighters with overmatching situational awareness, increasing their effectiveness and their survivability. Our Microsensor component and algorithm research will enable lighter, lower power, and highly effective microsensor components and algorithms for application to soldier-worn, vehicle-mounted, and unattended sensors.

- ***Electro Optic Smart Sensors, the eyes of the future force***: Smart EO sensors provide the future warfighter with even greater capability *to own the night*. Our focused research into higher temperature focal plane arrays, 3-D imaging LADAR, image fusion and ATR processing will extend the spectral dominance, lower the cost, and increase the information collection capabilities of these sensors.

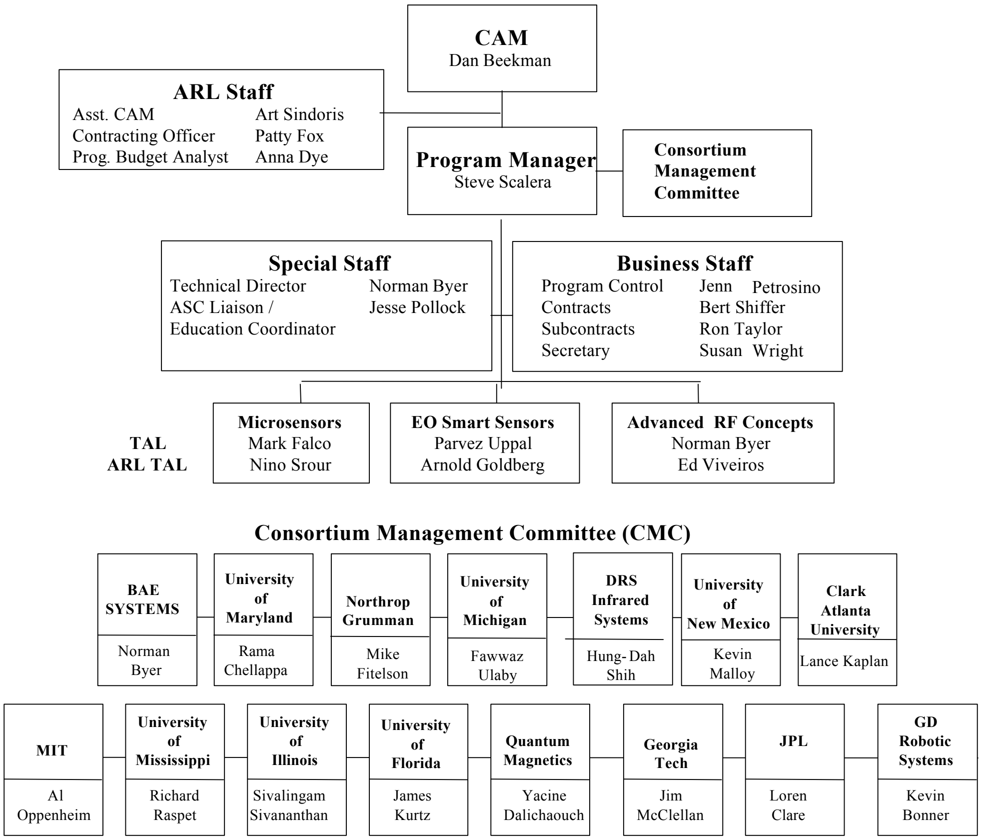
- ***Advanced RF Concepts, multi-function and compact***: Our research in new concepts for affordable electronically scanned antennas (ESAs) will enable Future Combat System (FCS) platforms to acquire, target, counter, and communicate all through the same small set of distributed apertures. Materials and advanced heterogeneous process technology development will enable a whole new class of power efficient microcircuits with significant dual-use impact for military systems and commercial products.

Advanced Sensors Consortium Members

The members of the consortium are shown in the following table.

Industry Partners: **BAE SYSTEMS**—a wide range of experience with tactical sensor design, integration, and production; as well as the management of complex research and development **Northrop Grumman**—a leader in defense electronics, systems integration and information technology with particular strengths in radar and EO technology **DRS Infrared Technologies**—a strong background in infrared focal plane array technology **Quantum Magnetics**—leading developer and manufacturer of research instrumentation for magnetic sensing **General Dynamics Robotic Systems**—as leader of the Robotic CTA, provides connectivity to that important Alliance
Academic Partners: **University of Maryland**—focuses on research in automatic target recognition and image processing **University of Michigan**—builds on a strong history of developments in solid state electronics and radar phenomenology **University of New Mexico**—a leading Minority Institution in high technology electro-optic materials and devices **University of Mississippi**—originators and leading innovators in acoustics **Georgia Institute of Technology**—provides automatic target recognition, and signal processing expertise **Massachusetts Institute of Technology**—strengths within this program include signal processing **University of Florida**—experience in radar signal processing and systems analysis **Clark Atlanta University**—leading private HBCU provides expertise in automated target recognition and data compression **University of Illinois at Chicago**—leader in epitaxial growth of IR materials
Federal Funded Research and Development Centers: **Jet Propulsion Laboratories**—JPL a major national laboratory brings a wide range of experience in autonomous systems

Advanced Sensors Organization



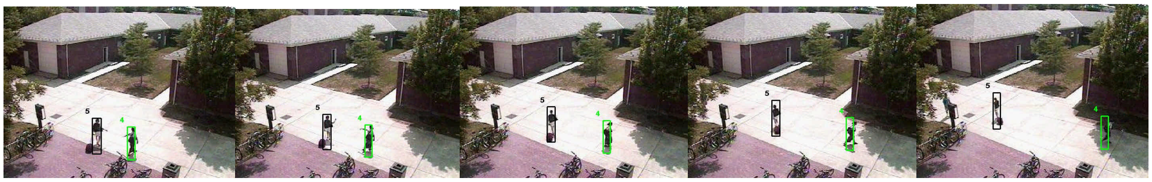
The Advanced Sensors Consortium is organized under Articles of Collaboration, which establish the terms for collaborative research among the members under the CTA program. BAE SYSTEMS, is the lead organization with four other industrial, one Federally Funded Research and Development Center (FFRDC) and nine academic partners.

Advanced Sensors Research Highlights

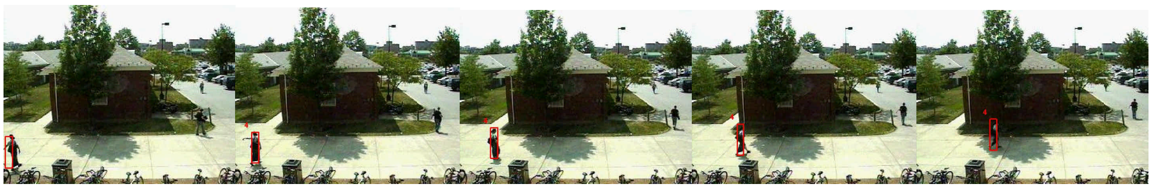
Technical Area 1: Microsensors

Distributed Tracking Using Multiple Cameras

To persistently track people and vehicles in a large area of interest, distributed imaging sensors must be used, since the field of view (FOV) of a single camera is limited. By using distributed cameras, when a target is leaving the FOV of one camera, but still remains in the monitored area, other cameras should be able to pick up this target and continue the tracking task. There are two major challenges here. One is to automatically calibrate a camera network with multiple arbitrarily placed cameras, and the other is to find correct target associations between video streams from different cameras when multiple targets are present at the same time. The Sequential Monte Carlo (SMC) algorithms we developed have been used to solve the camera network self-calibration problem. The posterior distributions of relative positions and orientations of the cameras are represented by related sample and weight sets. We also have developed an algorithm to solve the problem of target association or target cross-sensor hand-over. An example of distributed tracking via cross-sensor hand-over is shown below.



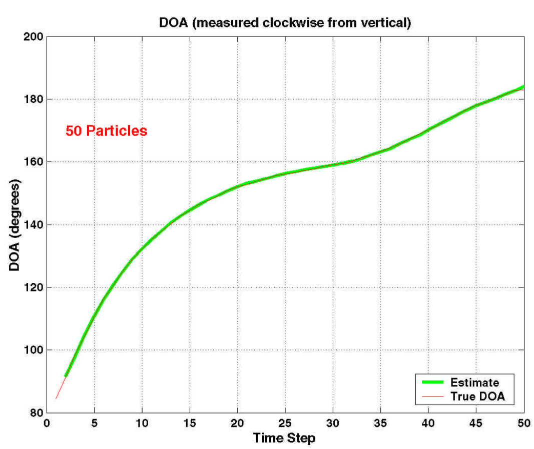
Two tracked people from camera 1.



One tracked person from camera 2.

Beamforming for Random Thinned Arrays

We are researching higher resolution beamformers in order to enhance the ability to find individual and multiple vehicles, count the number under observation and track their movement. A single DOA (Direction-of-Arrival) node that can track several targets accurately would reduce the communication cost between nodes that are trying to track a group of targets. Monte-Carlo Markov Chain (MCMC) methods provide the theoretical framework for tracking multiple vehicles directly from array measurements.



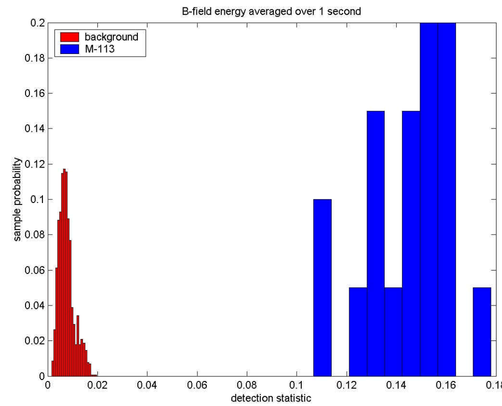
Particle Filter DOA estimate is virtually identical to the true track.

These algorithms are also referred to as “particle filters.” A DOA tracker has been implemented and tested for cases where a small circular array is tracking a target that can maneuver; performance compares favorably with the well-known standard, the MUSIC algorithm. In the multiple target case, particle-filter tracker-beamformer will significantly outperform beamformer-only algorithms, especially when the target bearings cross.

Improved detection range and tracking using magnetic microsensors

The objective of this research is to investigate the detection and tracking of military vehicles by analyzing field data recorded with a magnetic resonance (MR)-based magnetometer and magnetic tensor gradiometer.

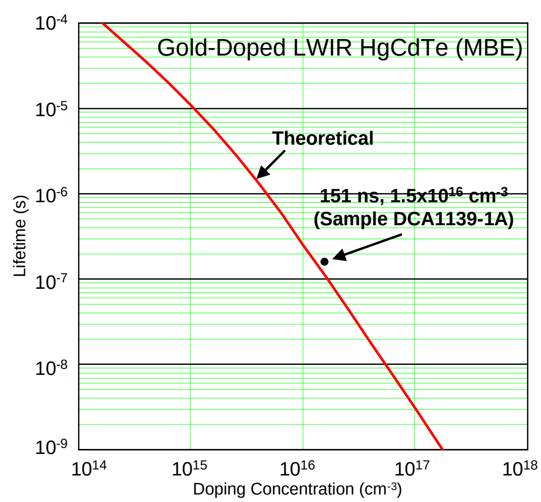
The magnitude of the B-field perturbation is a simple measure that provides very reliable proximity detection. Sample probability density functions for the B-field energy detection (BFED) have been found to resolve very well the null and non-null events (M-113, HEMTT, HMMWV, BMP-2, and BRDM). Detection ranges of at least 35 m for a HEMTT and 25 m for a BRDM have been estimated. Additionally, we were able to develop somewhat reasonable tracks on the larger vehicles (M-60, HEMTT, BMP-2) using gradiometer-processing techniques.



Sample probability density functions for BFED: "null" hypothesis and M-113.

Technical Area 2: Smart EO Sensors

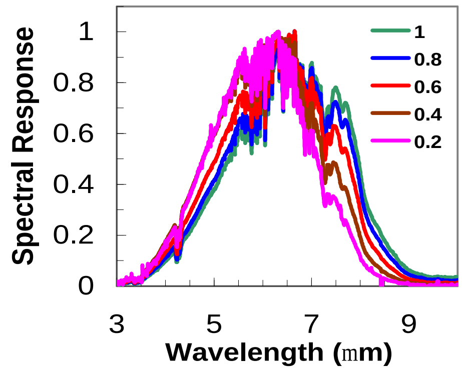
Improved Material for HgCdTe Higher Operating Temperature (HOT) Detectors. State of the art minority carrier lifetimes have been achieved for Au-doped HgCdTe. This is a very significant result because for the very first time such a high minority carrier lifetime has been obtained from an ex situ gold-doped LWIR HgCdTe sample. This is an important step towards the achievement of very low p-doped (5 × 1014/cm3) HgCdTe, which in turn will lead to higher operating temperature LWIR and MWIR detectors.



Minority carrier lifetime versus carrier concentration for LWIR $Hg_{1-x}Cd_xTe$ (x ~ 0.225).

Infrared Nanotechnology

This past year, advances in both infrared sources and infrared detectors based on quantum dot nanotechnology have been made. Quantum dot sources have been made to emit laser light at 2.0 µm at room temperature. To do this required modifying the shape of the quantum dots into "quantum dashes." Additionally, a significant improvement in quantum dot infrared detectors operating near 6 µm was achieved.

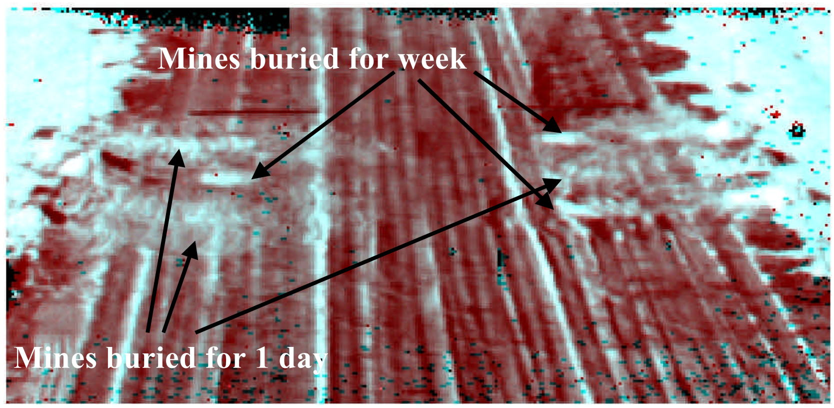


Tuning of a mid-wave quantum dot laser.

For the first time, tuning of the detector response was observed and measured. This tuning comes without the reduction in performance that accompanied previous tunable detectors. The 2.0-μm quantum dash laser result is an important step toward achieving an all-weather, eye-safe battlefield LADAR source, while the tunable detector result promises to reduce the cost of future hyperspectral imaging systems. These infrared sensors and sources are the key elements of the Army's technological mastery of the night.

Two-color LWIR/LWIR FPA for mine detection

Two-color LW/LW focal plane arrays were produced demonstrating their effectiveness in detecting freshly buried land mines. An improved two color FPA has been designed and is being fabricated for NVESD under as task order.

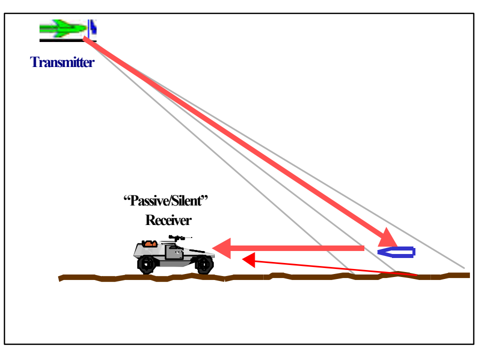


Two-color LW/LW fused image clearly demonstrates the usefulness in detecting freshly disturbed soil and hence any freshly buried mines.

Technical Area 3: Advanced RF Concepts

Multimeter Wave (MMW) Bistatic Radar Scattering from Terrain

Millimeter-wave bistatic radars can be used in Future Combat Systems (FCS) to provide active force protection and undetected surveillance of hostile targets. One configuration for this type of radar can have the transmitter mounted on a distant UAV and the "silent" receiver on an undetected ground-vehicle in the target vicinity.

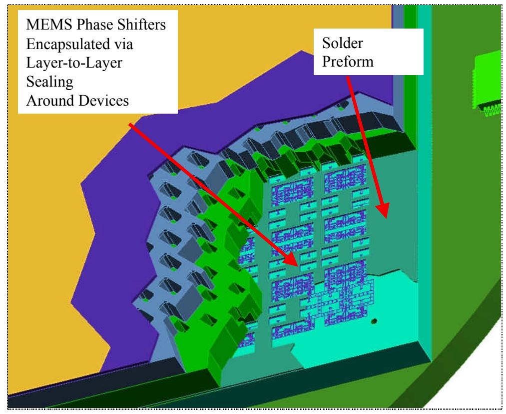


MMW Bistatic Radar Configured for Target Detection.

For these types of applications, the impact of clutter on the received MMW signal has not been examined before. A series of indoor measurements were conducted on rough soil surfaces using 35-GHz polarimetric, bistatic, instrumentation radar in order to characterize the radar response of clutter over the entire upper hemisphere for different illumination angles. The conclusions derived from these measurements were used to identify bistatic configurations and polarimetric features that enhance the detection of low-flying projectiles *via* bistatic radar.

Integrated Phase Control Module for Ka-Band ESA

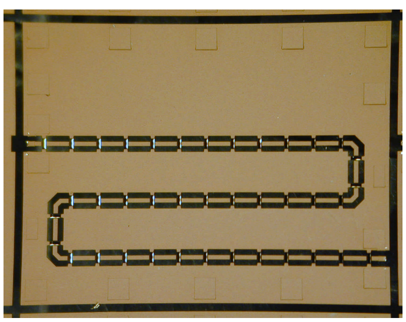
Affordable, MMW, active electronically-scanned arrays (AESA's) enable a viable FCS multifunction communications, air defense, self defense, and fire control aperture. Key to achieving low production cost are batch-fabricated micro-electromechanical system (MEMS) phase shifters integrated into a planar multi-layer liquid crystal polymer (LCP) substrate assemblies. LCP substrates have been specified and tested, and the compatibility and processes for successful fabrication of RF MEMS switches have been evaluated. Fabrication of various RF MEMS switch designs on LCP test substrates are underway.



Cut-away View of Batch Fabricated MEMS on LCP Layer and MEMS Encapsulation Concept.

Low-Loss Distributed Phase-Shifter at 24 and 38 GHz

Small linear phased arrays are needed to supply the elevation scan for multifunction electronically scanned array apertures. A highly integrated true time delay phased array network was demonstrated that uses only five identical 180° phase shifters in a 6-element array. The array employs varactor controlled distributed MEMS transmission-line phase shifters.



Distributed True Time Delay Phase Shifter.

We have successfully developed CPW transmission-line loaded phase shifters for 24 GHz and 38 GHz applications. At 37–40 GHz, insertion losses of 3.8–4.2 dB were achieved with phase shifts of 136°. We are currently packaging these phase shifters for insertion in a 10-element array that will be used in the ARL multifunction radar system. This technology offers the optimal approach to highly integrated multifunction RF systems.

Advanced Sensors Transitions

Examples of this year's technology transition activities are summarized below:

Development and Delivery of 320 × 256 Two-Color LWIR/LWIR QWIP Focal Plane Arrays for Mine Detection

In support of a CECOM/NVESD requirement for a focal plane array for the LAMD program, BAE SYSTEMS was contracted to supply a pixel-registered LWIR/LWIR QWIP focal plane array in a 320 × 256 pixel format. LWIR multi-band sensors have also been shown to be effective in defeating camouflage in targeting and surveillance missions. This work leverages the two-color QWIP technology developed by the Advanced Sensors Consortium.

Development of a Low Power Modular Acoustic and Imaging Sensor (MAIS)

BAE SYSTEMS was awarded a task order contract to develop a low power, modular acoustic and imaging sensor compatible with the common architecture for Micro Sensor II prototype electronics and the Modular Based Processing Unit package developed by the Advanced Sensors Consortium. The University of Maryland moving target indicator algorithm has also been ported to the system. This work heavily leverages the work performed within the Advances Sensors Consortium under the earlier Federated Labs Program.

Ka-band MHEMT MMIC Development

BAE SYSTEMS is executing a development cycle for MHEMT (metamorphic high electron mobility transistor) MMIC devices targeted at future Army Ka-band multifunction apertures operating within a nominal frequency range of 37-40 GHz. A variety of MMIC types have been designed, fabricated, and tested, including all T/R (transmit/receive) functions (power amplifier, low noise amplifier, switch, and phase shifter), thereby allowing high levels of integration to be achieved in the future.

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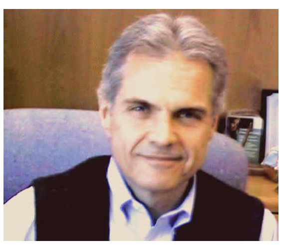
A Message from the Communications and Networks (C&N) Leads

Dr. John W. Gowens (ARL)

Collaborative Alliance Manager

The Army is committed to transformation toward a more agile and deployable force. Fundamental to the transformation is a future Objective Force with a tactical and strategic dependence on network centric warfare with potentially large numbers of unmanned components. The communications requirements for this newly conceived Objective Force are of unparalleled complexity. The Communications and Networks CTA performs communications research into the most difficult challenges facing the Army in migrating the force to complete network centric warfare. My goal is to transition the results of the CTA Communications & Networks research and provide advanced technologies for the future Army. The project results shown in this section are a sample of the types of transitions we made in the past year. I anticipate that many more transitions will be made as the consortium continues to produce exciting research results to support the transformation of the Army into a 21st Century fighting force.



Dr. Ken Young (Telcordia Technologies, Inc.)

Consortium Program Manager

The research vision of the consortium is to develop technologies that support a fully mobile, fully communicating, agile, situationally aware, survivable, deployable force with internetted C4ISR systems. The Objective Force will use large, heterogeneous, wireless communication networks. These networks will operate while forces are on-the-move using a highly mobile network infrastructure and under conditions of severe bandwidth and energy constraints. The technologies we develop will provide the Objective Force with secure, jam-resistant communications in noisy, hostile wireless environments.

Communications & Networks Research Focus

In order to achieve our research vision, the CTA C&N research focuses on the following four main technical areas, with cross-collaboration among areas:

- ***Survivable Wireless Mobile Networks***: develops technologies that ensure that these networks are self-configuring and self-maintaining, highly mobile, survivable, scalable, energy-efficient, performance-optimized and interoperable with joint and coalition forces.
- ***Signal Processing for On-the-Move Communications***: develops new communications technologies, focusing primarily on the lower layers of the communications protocol stack, to support efficient communications on the move.

- ***Secure Jam-Resistant Communications***: develops waveform signal processing technology to ensure reliable communications in environments which include dense, multiple access interference that may be generated from within the network, or by other systems which unintentionally interfere with the military network, and by hostile interferers.
- ***Tactical Information Protection***: develops technologies that provide automated, scaleable, efficient, adaptive, and secure information protection in wireless, multi-hop, self-configuring networks.

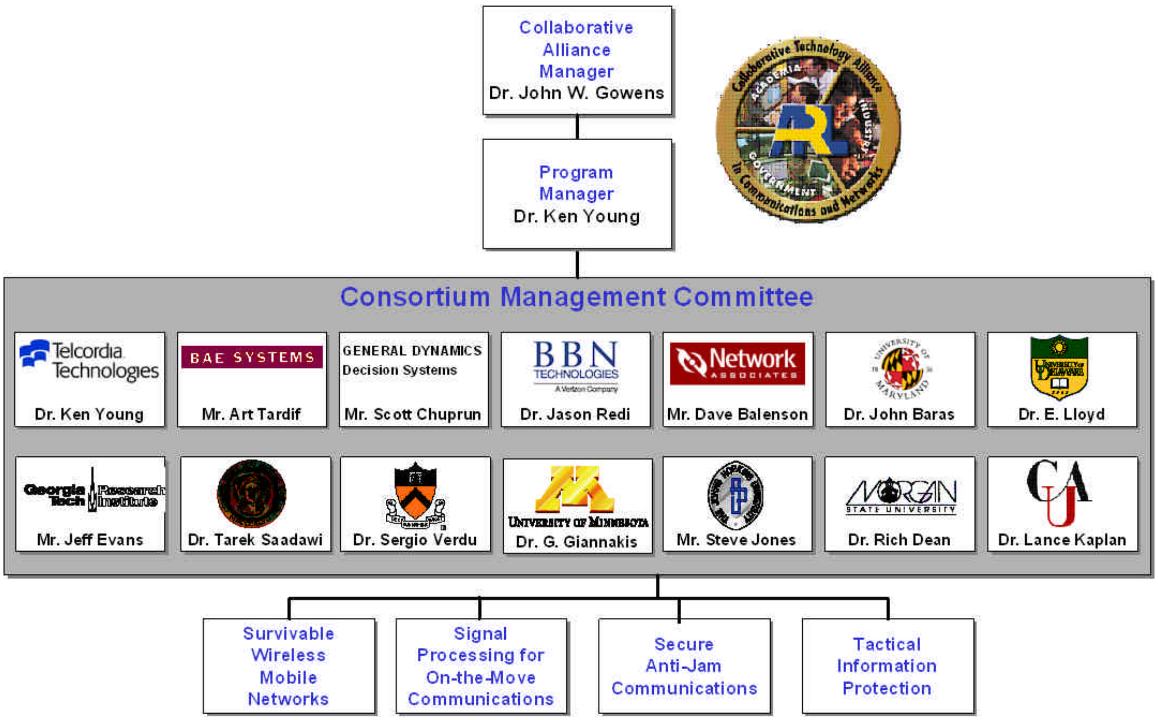
Communications & Networks Consortium Members

The members of the consortium are shown in the following table.

Industry Partners: **Telcordia Technologies**—the pre-eminent industrial R&D organization in communications and networking, and a leader in the development of standards **BAE SYSTEMS**—over four decades of aggressive technology innovation in advanced electronics systems for global defense, civil, and commercial electronics markets **General Dynamics**—a worldwide leader in military and commercial wireless communications products **Network Associates**—the world's largest network security and management software company, with NAI Labs advanced security research **BBN**—over 30 years of recognized innovation in networking research and deployment
Academic Partners: **University of Maryland**—a research leader in mobile wireless communications and networks, with excellence in government-university-industry partnerships **University of Delaware**—the nation's second most-wired campus with a long history of excellence in internetworking and communications **University of Minnesota**—world-class research and facilities in signal processing and communications **City College of New York** (CCNY)—a leading Minority Institution in communications and networking research **Princeton University**—with its world-renowned Ph.D. program, originators and leading innovators in multiuser detection technology **Georgia Institute of Technology**—a unique combination of academic, industrial, and government advanced research for telecommunications **Johns Hopkins University**—with its Applied Physics Laboratory, winner of more federal R&D funding than any other university **Morgan State University**—among the top U.S. universities in graduating African-American electrical engineers **Clark Atlanta University**—a leading private HBCU in science and technology research

Communications & Networks Organization

Telcordia Technologies leads the Communications and Networks CTA consortium. The other C&N Consortium Management Committee (CMC) members are shown below.

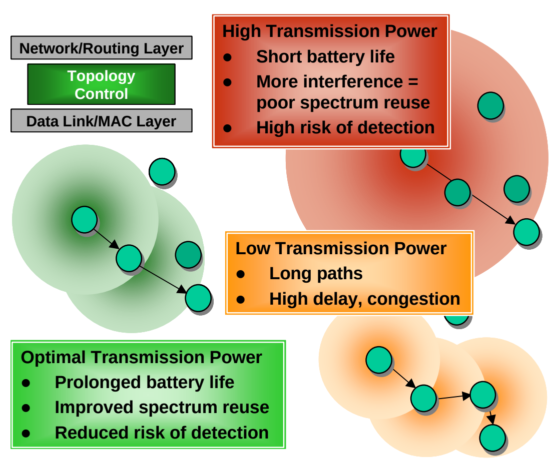


Communications & Networks Research Highlights

Technical Area 1: Survivable Wireless Mobile Networks

Topology Control for Wireless Networks

Energy efficiency is a principal factor in providing enhanced survivability for wireless networking devices. Typically, the greatest energy expenditure is due to the transmit operation. This is aggravated by the fact that most devices are designed to transmit with constant signal power. In many cases, depending on the proximity of devices, interference, and other factors, it is possible to maintain communication with a significantly less powerful signal, which in addition to conserving energy also reduces the risk of detection and the potential for interference, i.e. increases spatial spectrum reuse.

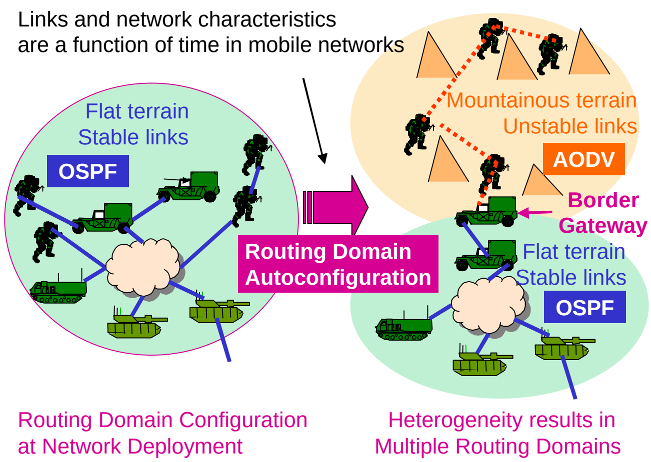


Effects of topology on energy efficiency.

From the network perspective, reduced transmit power leads to shorter packet hops and longer paths. This may result in increased delay and congestion, which could be unacceptable to certain network applications. To prevent such undesirable effects, it is necessary to satisfy certain network topology constraints (e.g., network diameter, etc.) when optimizing the transmission signal power. In general, this constrained optimization problem has been proven computationally unfeasible. However, we have designed heuristic-based solutions for several simplified cases (e.g., network diameter = 2) and are working toward combining these solutions with clustering techniques that would make it possible to construct an approximate global (network-wide) optimum using a multitude of local optima as building blocks. This will provide a scalable, distributed solution that can be employed by a wide range of mobile network systems.

Domain Autoconfiguration for Mobile Wireless Networks

Dividing the network into independent and homogeneous domains, with some abstraction of intra-domain information, is vital for the scalability and survivability of networking functions (i.e., routing, configuration, security and quality of service) in large heterogeneous networks (e.g. Future Combat Systems). Domains must be automatically configured to enable rapidly deployable networks and must adapt to network dynamics (e.g., topological changes or new mission requirements).

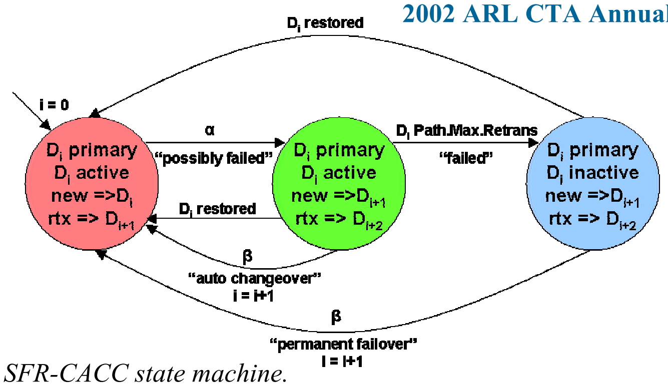


Adapting to network and environment dynamics through routing domain autoconfiguration.

During 2002, we designed a new, hierarchical domain architecture and created new algorithms to dynamically decide domain membership based on node mobility, roles and other metrics. We gave the first-ever demonstration of dynamic routing domain by enhancing CECOM MOSAIC IPAS. In our testbed, (also demonstrated at the 23rd Army Science Conference December 2002) we were able to automatically reconfigure the network into two independent routing domains starting from a single routing domain. Reconfiguration involves reconfiguring nodes with different routing protocols and enabling border router capabilities in the border node.

Innovative Transport Protocols

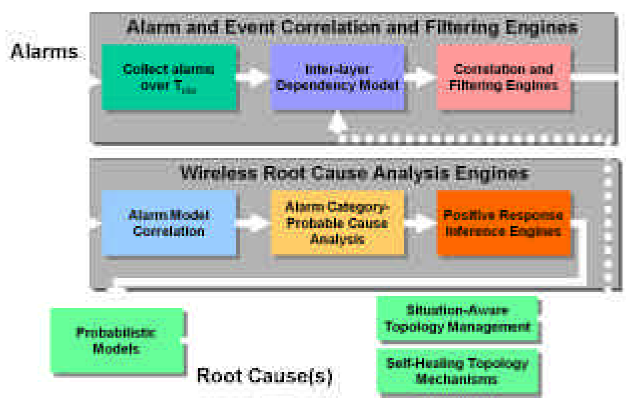
Traditional transport-layer protocols such as the Transmission Control Protocol (TCP) do not work well in battlefield environments. We enhanced two innovative transport services (multi-homing and multi-streaming) based on the emerging Stream Control Transmission Protocol (SCTP) Internet standard. These new services address several shortcomings of TCP. One contribution is an adaptive failover mechanism called the Split Fast Retransmit Changeover-Aware Congestion Control algorithm (SFR-CACC) that supports nodes with multiple radio interfaces, known as multi-homing, which TCP does not support. The SFR-CACC allows a node to efficiently switch transmissions between interfaces as network conditions change, while ensuring fairness among all SCTP users in terms of access to network resources.



SFR-CACC state machine.

We also developed an improved approach to detecting network congestion for SCTP using Explicit Congestion Notification (ECN). TCP uses a windowing method based on packet losses for controlling network congestion, but cannot distinguish between losses due to congestion, and losses due to network errors (e.g., weak transmission links or jamming). As a result, in a lossy wireless environment, TCP performance is poor. ECN decouples error recovery from congestion control, eliminating unnecessary retransmissions. When combined with Active Queue Management (AQM) in intermediate nodes, ECN provides higher thruput via more efficient congestion control.

Fault Localization and Root Cause Analysis for Battlefield Network Management



High-level architecture of network management system.

Detecting and localizing faults in tactical mobile wireless networks is difficult for a variety of reasons, including their ad hoc nature, random/sporadic failures due to attacks, and multiple, possibly correlated failures. Thus, it is important to have an efficient fault management system that performs dynamic and rapid fault localization and provides self-healing mechanisms to mission-critical applications.

We developed efficient fault inferencing algorithms targeted at performing dynamic and rapid fault localization in Future Combat Systems networks. Our multi-layered model uses Bayesian techniques to capture the dependencies that may exist between entities in multiple nodes and in multiple protocol layers. The root causes generated by these inferencing engines will be used to drive battlefield network topology management systems and self-healing mechanisms. Situational-aware topology management and service survivability mechanisms ensure uninterrupted service in the Army's mobile ad hoc battlefield networks. A paper describing this research was selected for a best paper award at the 23rd Army Science Conference in December 2002.

Technical Area 2: Signal Processing for Communications-on-the-Move

Multiple Access Techniques

Future combat communication systems must support many users communicating in unpredictable, asynchronous ways, using waveforms that are much more complicated and robust that those used for commercial wireless applications. We are developing advanced Multiple Access techniques for Frequency Hopping Multi-Tone waveforms to dramatically increase receiver robustness and capacity, using Frequency Hopping Multi-Carrier Systems, Clustered OFDM, and Advanced Signal Designs for Multiple Access.

Beyond these methods, progress has been made in developing low complexity multi-user detection systems to maximize the number of radio devices that can use the spectrum without placing additional burdens on the size, weight, and power consumption of the soldier radio.

MIMO receiver and transmitters.

Multi-Input Multi-Output (MIMO) Systems

We are developing advanced Multi-Input, Multi-Output Systems to efficiently support very high data rates over mobile, non-line of sight channels by exploiting multiple antennas at each end of the link and space-time coding methods. In 2002, we performed an MLJD MIMO demonstration in which we showed that OFDM MLD MIMO systems can dramatically outperform traditional layered-space-time approaches. In another experiment using Dynamic Antenna Grouping, we demonstrated that by using novel MIMO channel metrics, we could achieve communications performance which approached MLJD results, but at much lower complexity than using MLJD. Finally, our over-the-Air MIMO measured results highlighted the benefits of MLD and Hybrid Approaches developed in real-world channels.

Cross Layer and Novel Concepts

We are developing the critical links between layers required to fully exploit advanced MIMO methods, Multiple Access Technologies, and waveforms. Energy Aware Networking, Multi-Carrier Random Access, and Signal-Processing-Aided Media Access Control are examples of projects which exploit efficiencies spanning the traditional layers of communications networks. We are also investigating novel concepts in communications, including advanced free space optical networks and exploitation of MIMO techniques for airborne interrogation of sensor fields.

Technical Area 3: Secure Anti-Jam Communications

Wideband Source Localization

Researchers at Clark Atlanta University review results of UWB algorithms.

In an effort to better understand Wideband Source Localization, Clark Atlanta University (CAU) has been working in close collaboration with the Georgia Institute of Technology (GIT) to develop novel techniques to scan the bandwidth over time, frequency and space for both friendly and hostile communications. The radio spectrum is becoming increasingly complex by emerging technologies that will make traditional detection techniques ineffective. Motivated by the recent advancement of ultra-wideband (UWB) technology, CAU and GIT have been developing wideband direction of arrival (DOA) algorithms so that the location of UWB radios can be determined. Over 2002, the two universities have developed and analyzed a multistage delay beamformer that can quickly scan over angle by pruning processing to resolve benign sectors. A selection of the additional projects are briefly highlighted on the following page.

Blind Frequency Hopping (FH) Source Separation

We developed a method for blind reception of multiple FH signals to provide robust reception in extremely active FH environments. The method performs: preliminary hop detection, using nonparametric tools; localization using advanced multidimensional low-rank decomposition and harmonic retrieval tools; robust beamforming to focus on a single FH signal; and estimation of single-user hop timing, dwell interval estimation, tracking, and demodulation.

Sectored vs. Adaptive Array Performance

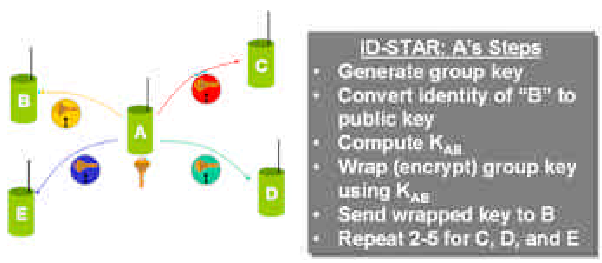
With the goal of improving performance without increasing complexity, we compared the performance of adaptive antenna arrays versus sectored antennas in mobile-to-mobile non-line of sight (LOS) communications. We determined the node capacity with multiple-user interference in mobile-to-mobile channel; single user detection assumed and investigated MIMO capacity with sectored antennas.

Optimal Packetization for Channel Estimation and Tracking

New classes of Packet Structures will optimize header and pilot symbol locations for channel estimation, and will improve Low Probability of Intercept (LPI) and Anti-jamming (AJ) performance. Furthermore, the standard Packet Format is not for channel estimation and tracking performance, and is vulnerable to interception and jamming. To meet these challenges, we developed LPI/Low Probability of Detection (LPD) training strategies that minimize channel estimation and tracking error.

Technical Area 4: Tactical Information Protection

Identity-Based Group Keying Protocol

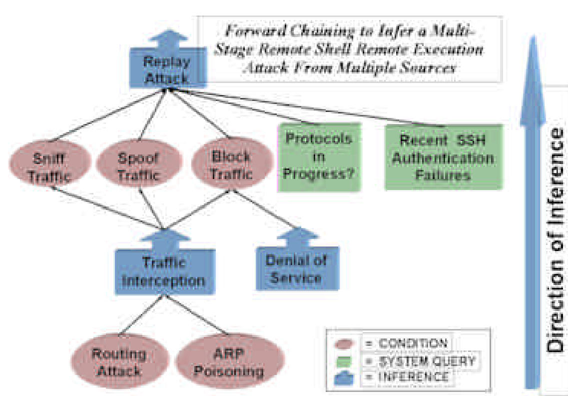


ID-STAR group keying protocol.

We developed a group key transport protocol called ID-STAR that uses identity-based keys to reduce required communications by up to 50% versus comparable public key protocols when certificates are exchanged. The communications reduction significantly reduces energy and latency associated with key management.

Message Authentication Streams

We reduced authentication tag size by over 50% (in some scenarios) while maintaining strong security, thus reducing energy and latency in low-data-rate Army networks. The approach we take to achieve this is to authenticate packets at the physical layer based on correct pseudorandom code (PN) sequence correlation. We append the spreading code generated from key and data, thus increasing reliability by reducing false verification failures.

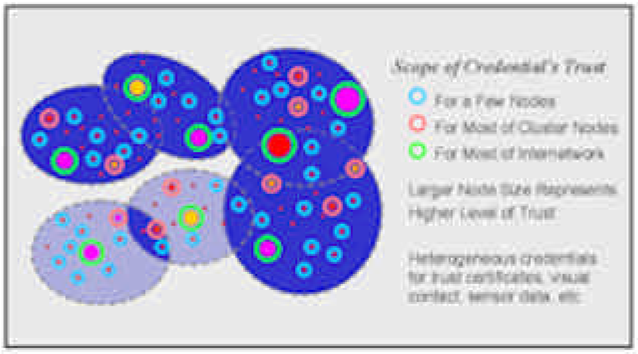


Steps in complex attack reasoning.

Complex Attack Reasoning

We developed a description logic approach needed to build a correlation engine for detecting complex multi-stage network attacks. This allows a dynamic view of the infospace that is computationally tractable and responsive to an ad-hoc Army tactical network facing evolving enemy attacks.

Distributed Trust Establishment Algorithm



Distributed Trust in Army mobile networks.

Distributed trust is applicable to Army mobile networks with dynamic topologies and not to centralized security services. To meet this requirement, we developed a trust distribution scheme based on Freenet-like evidence distribution and retrieval. We employed “Swarm intelligence” to autonomously distribute trust credentials, and applied fusion and reinforcement "on-the-fly" to enable dynamic trust transfer. We adopted a balanced combination of reinforcement and exploration, recomputing the trust metric via limited range back-chaining.

Communications & Networks Technology Transitions

Examples of this year’s technology transition activities are summarized below:

- ***Domain Autoconfiguration for the MOSAIC ATD***: Telcordia designed and implemented a Domain Announcement Protocol (DAP) that will be used to support the U. S. Army CECOM's Multi-functional On-the-move Secure Adaptive Integrated Communications (MOSAIC) Advanced Technology Demonstration (ATD). When combined with an improved version of the Dynamic Configuration Distribution Protocol (DCDP), DAP will support automated configuration and re-configuration of domains for mobile wireless networks in the MOSAIC ATD.

- ***Optical Sensor Networking for Laser Communications and Atmospheric Channel Characterization***: The University of Maryland was awarded a contract to develop a specialized network of sensors (SNS) capable of real-time precise characterization of free-space optical communications channels. The SNS suite will be integrated into the ARL atmospheric laser optics testbed, creating an infrastructure for evaluation of sensors and communications systems under actual atmospheric conditions. The result of the effort will be a complete sensor network testbed facility for high data rate communications experiments and evaluation of the potential of free-space laser communications for Objective Force Communications needs.

- ***Spectrum Awareness***: General Dynamics was awarded a contract to transition spectrum scanning and decomposition algorithms to support tests of airborne waveform adaptation. The improved spectrum awareness software will be integrated into the DMR radio system and evaluated in a series of flight tests.

- ***Identity-Based Group Key Management for the ARL Sensor Net Radio***: Network Associates Laboratories designed and specified the security architecture for the ARL low energy software defined radio that provides communication for this sensor network. This architecture uses a C&N CTA-developed, identity-based group keying protocol called ID-STAR that significantly reduces communications for key establishment. Network Associates Laboratories also developed and delivered to ARL a Maurer-Yacobi key generator that generates and provides identity-based public/private keypairs for use in the sensor radio.

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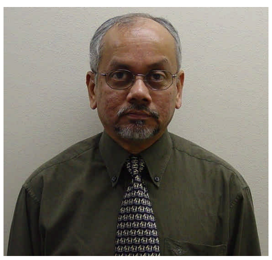
A Message from the Power and Energy (P&E) Leads

Mr. John Hopkins (ARL)

Collaborative Alliance Manager

Power & Energy technologies are pervasive, enabling and critical for transforming the Army. The technologies associated with Power Generation, and Power Control and Distribution, technologies addressed by the Power & Energy CTA, directly impact the operations of all Army and DoD elements.

Success in these technologies is critical in helping the Army meet operational and performance goals within the Objective Force Warrior, Future Combat System and the Objective Force initiatives.



Dr. Mukund Acharya (Honeywell Engines, Systems & Services)

Consortium Program Manager

Consortium research objectives will advance the fundamental science and understanding of efficient compact power and propulsion technologies needed to develop affordable, state-of-the-art systems required by the Army's Objective Force. To meet the Army's vision, compact and efficient power and propulsion systems are required to assure a survivable, affordable air-insertable, sustainable combat force with a small logistical footprint. The Consortium is focused on increasing the energy density of soldier portable power systems by 5–10 times over current level of 200 W-hr/kg, and of vehicle propulsion systems by 3–5 times over current diesel engines, while reducing usage of fossil fuel by 75%.

Power & Energy Research Focus

In order to achieve our research objectives, the Power & Energy CTA research focuses on three technical areas:

- ***Portable, Compact Power Sources (non-electrochemical)***: develop enabling technologies for revolutionary, non-electrochemical soldier power sources, with 10X greater energy density than current batteries and capable of meeting the power and energy requirements of the Objective Force Warrior.
- ***Fuel Cells and Fuel Reformation***: develop enabling technologies for soldier portable fuel cell systems, including fuel processing for hydrogen generation. Provide enabling technologies for logistics fuel reformation and fuel cells for vehicle propulsion.
- ***Hybrid Electric Propulsion and Power***: develop enabling technologies supporting efficient, compact, lightweight energy conversion and electric power conversion and conditioning for Future Combat System (FCS) and robotic platforms.

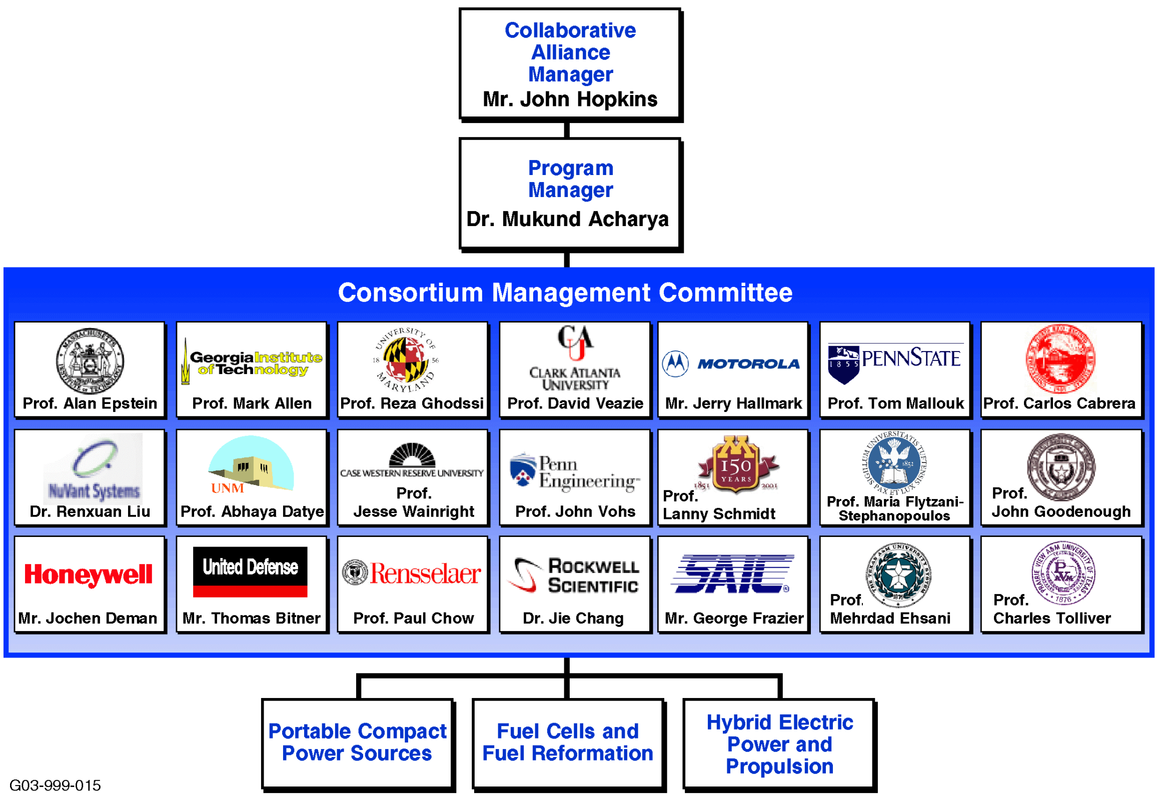
Power & Energy Consortium Members

The members of the Consortium are shown in the following table.

Industry Partners:
Motorola—DMFC membranes, DMFC/RHFC systems and integration
NuVant—Catalysts for DMFC and RHFC
Honeywell—Consortium lead, high-speed ceramic turbogenerator
UDLP—Turbo-electric compounded diesel, DC-DC converter
Rockwell Scientific—Extended matrix converter
SAIC—System simulation and integration, electric machine drives
Academic Partners:
MIT—Micro gas turbine and electrostatic generator
Georgia Tech—Electro magnetic generator
U of Maryland—Micro-fabrication technology
Clark Atlanta U—Electro magnetic generator
Penn State U—Catalysts for DMFC and RHFC
U of Puerto Rico—Catalysts for DMFC and RHFC
U of New Mexico—Methanol steam reforming catalyst support
CWRU—High temperature membrane electrode assemblies
U Penn—Direct oxidation anodes for SOFC with logistic fuels
U of Minnesota—CPOX reactor and catalysts for logistic fuel reformation
Tufts U—High temperature fuel de-sulfurization
U Texas at Austin—Low temperature SOFC materials cathode and electrolyte
RPI—SiC devices
Texas A&M—Electric machine drives, intelligent controls
Prairie View A&M—Electric machine drives, modeling and simulation

Power & Energy Organization

Honeywell leads the Consortium, and the Consortium program manager has overall management responsibility for the Consortium, the exchange of information between the technical teams ARL and OGAs, as well as all the management, reporting, and planning functions. He serves as the single-point-of-contact between the Consortium and the ARL Collaborative Alliance Manager (CAM). At the same time, the Consortium provides for, and encourages the direct collaboration and exchange of ideas between Consortium members, ARL and OGA personnel in the conduct of the research activities.



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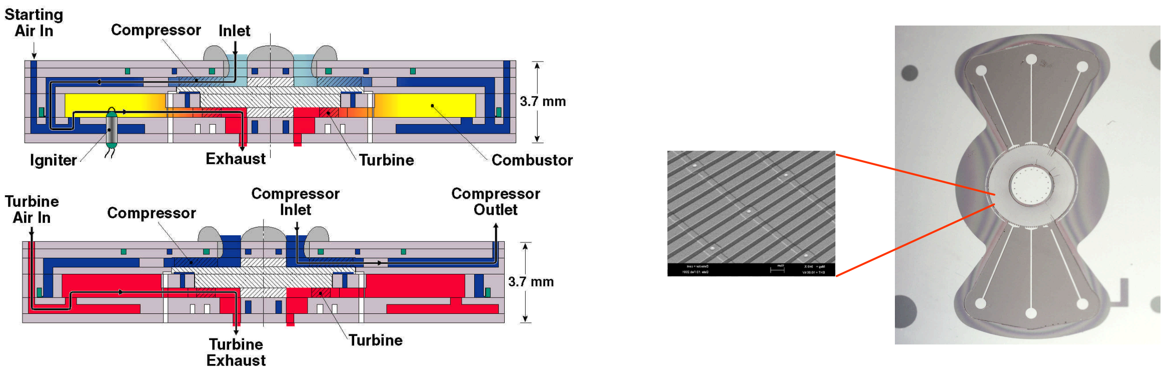
Power & Energy Research Highlights

Technical Area 1: Compact, Portable Power Sources

Hydrogen Fueled, MEMS Gas Turbine Engine and Generator

An upcoming milestone is the demonstration and testing of a first generation MEMS-based, chip-scale micro gas turbine engine. To meet this goal, research continued on component technologies required for advanced, improved performance, and integrated versions of these devices.

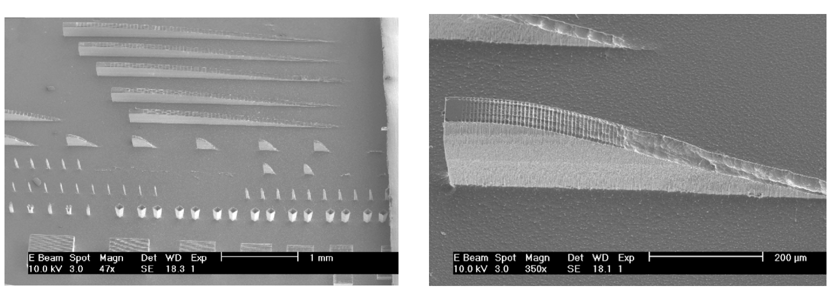


Demo Engine, Microturbocharger, and Electrostatic Induction Microgenerator.

Research was directed at improving turbomachinery efficiency, extending the operating temperature range and performance of the electrostatic generator, improving the performance and reducing the complexity of air bearings, increasing the temperature capability of the turbine structure, extending the combustor to include hydrocarbon fuel, realizing the promise of magnetic generators, and developing engine controls. A substantial effort was also undertaken to expand microfabrication process capabilities and to implement strict process controls to enhance robustness of the microfabrication process. Initial operation of a microturbocharger version of the engine (in which the compressor discharge and turbine inlet gas flows exit the chip separately) was demonstrated. The microturbocharger is a research tool to measure the performance of the bearing system and the turbomachinery fluid mechanics.

Variable Height Precision Deep Reactive Ion Etching (DRIE) Technology

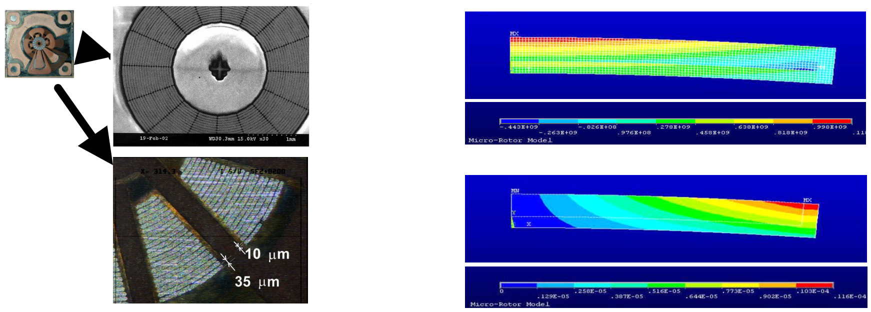
Work focused on development of a gray-scale microfabrication technology to create variable-height, precise, high aspect ratio structures in silicon. This will allow fabrication of three-dimensional turbine and compressor blades that will enable significantly improved performance.



Reactive Ion Etching of Silicon Structure with Photoresist Patterned by Gray-Scale Lithography.

MEMS Magnetic Generator Technology and Structural Design for High Speeds

Magnetic generators are being considered for their lower losses and favorable voltage and current levels. This project involves development and implementation of fabrication technology for low and high temperature MEMS-based magnetic generators, and the electromechanical design of devices based on this technology. New fabrication processes were developed and demonstrated for laminated magnetic microstructures that result in lower eddy current losses.



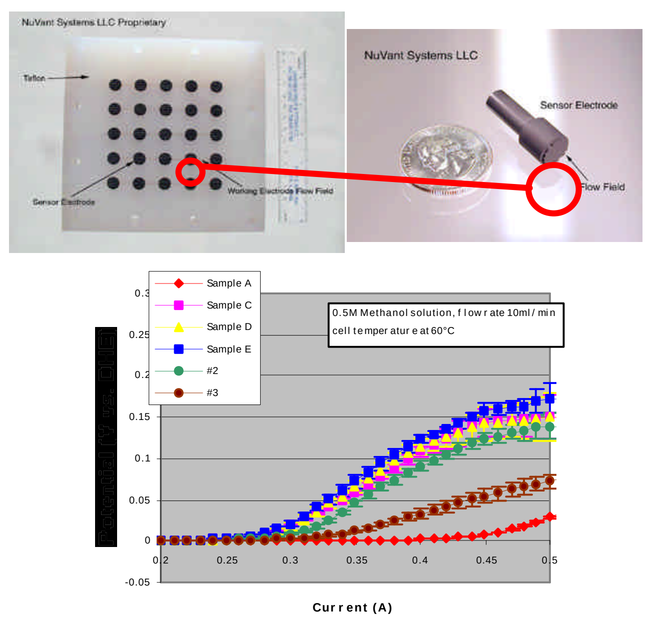
Laminated Magnetic Microstructures Reduce Loss; Finite-Element Analysis of Magnetic Rotor.

Magnetic generators have significant three-dimensionality and material challenges compared with their electrostatic counterparts. In addition, many magnetic materials do not have the specific strength of silicon. This imposes the need for tightly coupled structural design and optimization of the magnetic machine with the electromechanical design. The figure shows a sample result from a magnetic rotor thermo-structural analysis. Such results are being used to guide the geometric design of the generator.

Technical Area 2: Fuel Cells & Fuel Reformation

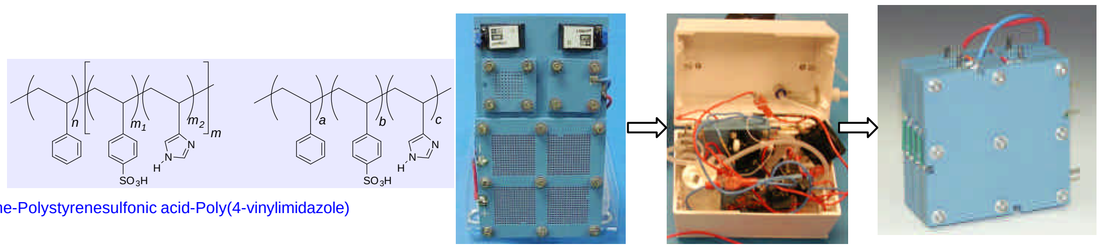
PEM Fuel Cells

Good progress has been made relative to research milestones. Electro-catalyst synthesis, test methodologies and fixturing have been established and several screening runs have been done with good agreement between screening, array, and single cell testing.



Fixtures for Combinatorial Catalyst Synthesis/Screening and Test Results.

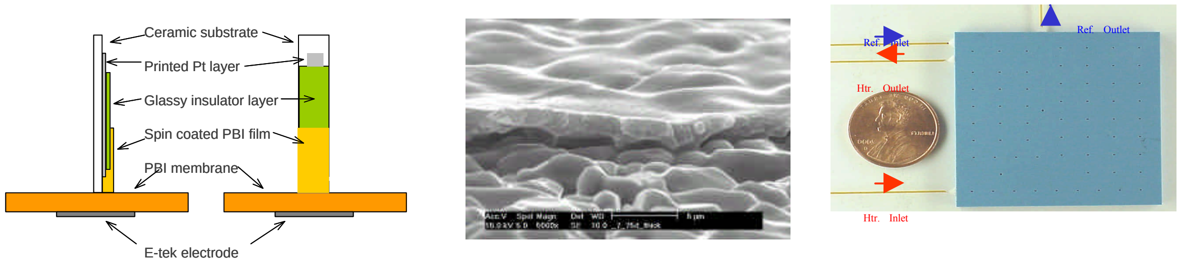
New polymerization approaches to develop improved membranes for direct methanol fuel cells have shown initial success. Tests with DMFC systems under varying load were successful in providing an improved understanding of cell degradation issues.



Polystyrene-Polystyrenesulfonic acid-Poly(4-vinylimidazole)

DMFC Polymer Membrane Precursors and Three Generations of DMFC Hardware.

Processes were developed to deposit catalysts directly on ceramic structures, a requisite for the development of effective reformed hydrogen fuel cells. Continued refinement of the 2.5W fuel processor has to date has produced 4.8A of H_2.

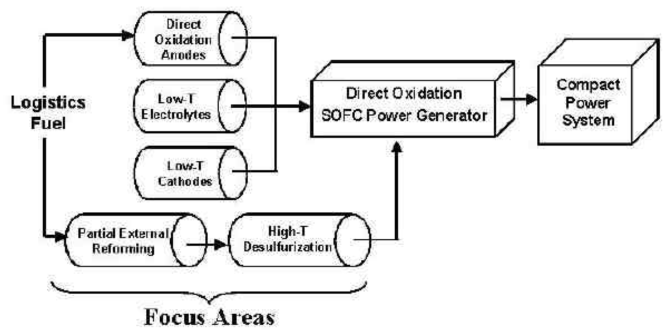


Microband Test Cell for RHFC MEA Characterization and Generation 2 Fuel Processor.

A new process using glass substrates, new insulation materials, and sputtered Pt film was developed in the preparation of microband electrodes for the high-temperature membrane electrode assemblies.

Solid Oxide Fuel Cells and Logistic Fuel Reformation

This task area focuses on fundamental research important for the development of small, solid oxide fuel cell (SOFC) systems that operate directly on logistic fuels, such as JP-8, that are suited to meet the mobile and stationary power needs of the military. Key technological hurdles being addressed include: development of electrolytes and cathodes that have high performance at temperatures between 500 and 700°C; development and optimization of direct oxidation anodes that are compatible with the low-temperature electrolytes; development of small, highly efficient, catalytic partial oxidation (CPOX) reactors for partial reformation of logistic fuels; development of sorbents for the removal of sulfur from logistics fuels at high temperatures. The figure provides an overview of the focus areas of this research program. Technical summaries of the research activities and significant accomplishments:



Approach and Technologies for SOFCs and Logistics Fuel Reformation.

Direct Oxidation Anodes: Direct oxidation of hydrocarbon fuels using Cu/Ceria cermet anodes in SOFCs with low-temperature electrolytes (samaria-doped ceria (SDC) and scandia-doped zirconia (ScZ) has been demonstrated.

Low-Temperature SOFC Materials: Several mixed ionic-electronic conducting oxides have been evaluated as cathode materials for low-temperature SOFCs. Power densities in excess of 1 W/cm^2 have been obtained in SOFCs with $SrCo_{0.8}Fe_{0.2}O_{3-d}$ cathodes and LSGM electrolyte while operating on H_2.

CPOX Reactor and Logistics Fuel Reformation: Prototype CPOX reactors have been constructed and their performance evaluated. Preliminary results for decane are very promising and show that higher hydrocarbons can be reformed to CO and H_2 or light olefins with high selectivity using a Rh catalyst.

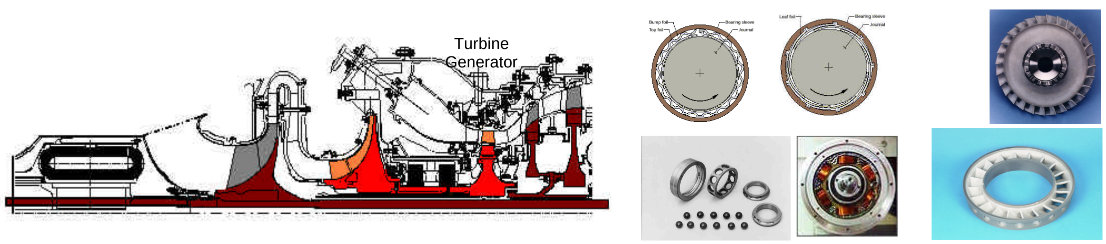
High-Temperature Fuel Desulfurization: A series of potential high-temperature sulfur adsorbents have been evaluated. Ceria doped with Cu has been shown to have high sulfur adsorption capacity in the appropriate temperature range.

Technical Area 3: Hybrid Electric Propulsion and Power

The overarching goal for research in hybrid electric propulsion and power is to support the Army's vision for its next-generation forces. This vision emphasizes the rapid deployment of more lethal and survivable systems with smaller logistical footprints than current forces. The Future Combat Systems (FCS) program is currently researching the force structures that will make that vision a reality. One of our major objectives is to maximize the coupling of research conducted in this area with the FCS program. Further, we will assist in the development of component and device technology for the systems and subsystems that will make hybrid electric combat power systems practical and efficient future battlefields. Our technical approach is multi-pronged: (a) investigate advanced, more compact and efficient power converters (i.e., engines & fuel cells and various combinations) which can utilize high sulfur logistics fuel; (b) improve the state of the art for silicon-carbide-based devices for power electronics applications; (c) develop systems which effectively utilize both of above technology advances. A brief summary of summary of activities in these areas follows:

High Speed Ceramic Turbogenerator

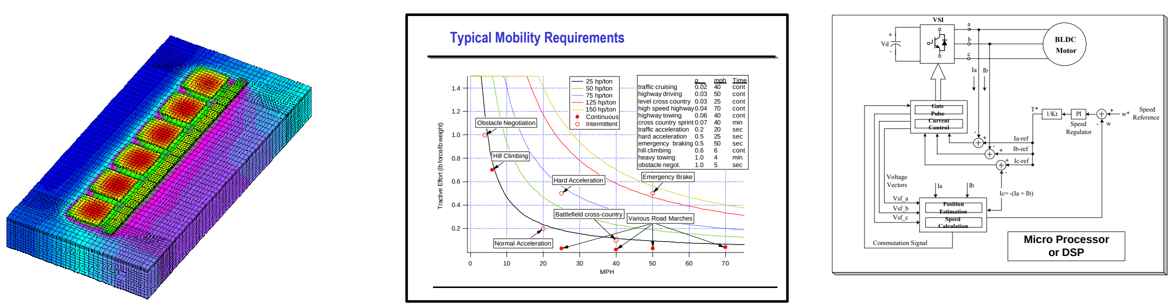
A conceptual layout for a high-speed, gas-turbine-based turbogenerator in the 500 kW class was completed. Candidate ceramic blade coatings to enable high-temperature turbine operation, as well as high-speed generator approaches were identified; preliminary bearing approaches were chosen.



Layout of Notional High Speed Turbogenerator and Examples of Components.

Silicon Carbide Devices

Work in this area focused on (a) improving fabrication techniques and thermal management for SiC devices; (b) development of test converter systems for utilization of SiC devices for matrix converters, DC-DC converters, motor-drive converters and advanced motor designs; (c) development of validated models for performing designs with SiC devices.



Finite Element Thermal Analysis of Advanced Si/SiC Hybrid Switch (left); Torque-Speed Map Showing Typical FCS Mobility Requirements (center); Sensorless Motor Drive Schematic (right).

Machines & System Analysis

The objective of the system design and modeling tasks was to determine the most promising insertions of these technologies for future Army applications, such as Future Combat System (FCS) and Land Warrior. During the course of the year, design goals for traction motors for a notional 15-ton vehicle were defined. A comparison of two alternative power distribution schemes using matrix converter and DC link systems was carried out, and a conceptual design for a switched-reluctance motor controller for reduced torque ripple was completed.

Power & Energy Technology Transition

During the past year, we conducted a task for the Natick Soldier Center to examine designs of methanol-based fuel-cell systems for a soldier application. The Army has a need for lightweight, inexpensive, and very high energy-density power sources that perform better than current primary or rechargeable batteries. Hybrid systems that combine a methanol fuel cell with a rechargeable battery are being evaluated as one possible solution. Any new solution must demonstrate an improvement over the baseline power source (batteries) to justify their use. One of the goals of this task was to demonstrate, on paper via design studies, that a methanol fuel cell hybrid system is an improvement over batteries for specific devices currently in use by the Army. Three proposed soldier applications were used for the study.

Three Soldier Applications

Power (Tx:Rx:stdby)	ICOM-F3S	AN/PRC-148	AN/PRC-119
Tx Power (W)	12.48	16.00	34.80
Rx Power (W)	2.4	3.7	8.76
Standby Power (W)	0.58	2.99	8.58
Average Power (W) (3.3:3.3:93.3)	1.04	3.40	9.46
Average Power (W) (0.8:0.8:98.3)	0.69	3.10	8.80
Average Power (W) from Field Exp. *	0.34-0.66	1.8	5.3
Average Power (W) std (10:10:80)	1.95	4.36	11.22

Data and operational info provided by Scott Feldman July 23, 2002
Additional data provided by Scott Feldman on Sept 24, 2002

*In general, the radio is on all the time during a mission in the stand-by mode. Time it takes to transmit a message is about 6 seconds, on average. Time it takes to receive a message is also about 6 seconds. Duty cycle is extremely variable, depending on the mission and the responsibility of the particular soldier using the radio. Estimates range as low as one message transmitted every two hours, to messages being transmitted 20 times an hour. The average is about 5 times per hour.

Specifications for Three Current Army Radio Applications.

DMFC and RHFC designs were created for the Natick program in order to examine current state of the technology and its applicability to soldier applications for the future. As an example, for a detailed design decision on the DMFC, a 0.7 W battery charger for the ICOM-F3S was completed.

To show the broad range of capability, a 20W central power source was then chosen for the second DMFC design in order to best show the higher energy and power densities which are achievable with a DMFC system even at higher power. With the technology as it stands today, we would be unable to achieve a DMFC battery replacement. However, projected future improvements and miniaturization will allow for this DMFC architecture in any future systems (3–5years). A detailed tradeoff was conducted to examine the relative merits of using direct methanol (DMFC) and reformed hydrogen (RHFC) fuel cell systems. At the lower power levels (one to a few watts), the DMFC systems seem to offer the better energy and power densities due to high volume overhead requirements of the insulated RHFC system and due to the balance of plant is virtually equivalent in the both systems. At the 20W level, the energy density performance of the systems is almost identical, but cost trades need to be considered, especially with respect to entering the commercial market with a cost-competitive product. It is at the 20W level that the RHFC system becomes more attractive than the DMFC, primarily due to cost considerations of current platinum pricing.

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A Message from the Robotics Leads

Mr. Charles Shoemaker (ARL)

Collaborative Alliance Manager

New realities demand innovative concepts to focus the talent of industry and academia on the critical technology needs of the Army. In particular, recent advances in commercial technologies demand a new approach to Army laboratory operations that will allow researchers to focus on Army needs, while leveraging the best of commercial technology advances. The Robotics Alliance is a unique member of the ARL CTA family, conducting applied research, funded with 6.2 RDT&E funds, critical to enabling development of the Army's Objective Force. The Alliance also has a direct responsibility, through the Office of the Secretary of Defense Joint Robotics Program, to provide advanced ground robotics technology to each of the armed services. As an applied research program, the Robotics CTA is focused on rapid technology development, working with soldiers to focus research into areas that will have both immediate and long term payoffs, gaining immediate feedback on new concepts, hardware and software.

Mr. Scott Myers (Vice President, General Dynamics Robotic Systems)

Consortium Program Manager

The Robotics Collaborative Technology Alliance (RCTA) focuses on technology required to permit inanimate systems and subsystems to perform in a seemingly human fashion. It is a systems-based discipline, combining perception, plan-behavior generation, and execution in a systematic, controlled fashion to achieve a designated goal with varying degrees of human interaction. To support the Army Vision of the development of the Objective Force and the Army's role as lead service for DOD ground mobile robotics technology, this alliance focuses on enabling high-speed, autonomous mobility in unstructured environments.

Robotics Research Focus

In order to achieve our research vision, the CTA Robotics research focuses on four technical areas:

- ***Advanced Perception for Autonomous Mobility***: We conduct research aimed at developing robot perception, navigation, and cooperation technologies to enable unmanned systems to join the force structure as effective members. Our focus is placed on the perception of salient features to enable the vehicle to execute tactically significant behaviors, while providing robust all-weather operation.
- ***Intelligent Control Architectures and Tactical Behaviors***: This area focuses on developing and enhancing a network-centric architecture that supports the planning and control of robotic resources (internetted unattended ground sensors (IUGS), unmanned ground vehicles (UGVs), unmanned aerial vehicles (UAVs), etc.) in battlefield environments, including the development of specific behaviors and skills for autonomous implementation by unmanned systems that will be necessary for successful operation in tactical environments.

- ***Human-Machine Interface***: The main research objective of this area is to develop the underlying technologies that will reduce operator workload and provide an optimal distribution of control between soldiers and unmanned systems. Context-sensitive multi-modal interface technologies will be used to enable operators to assess situations rapidly and respond in an effective manner.
- ***Modeling, Simulation, and Experimentation***: Modeling and simulation will be used iteratively with experimentation to identify high-payoff technologies and evaluate the effectiveness of new components, providing the driving force for directing the CTA research.

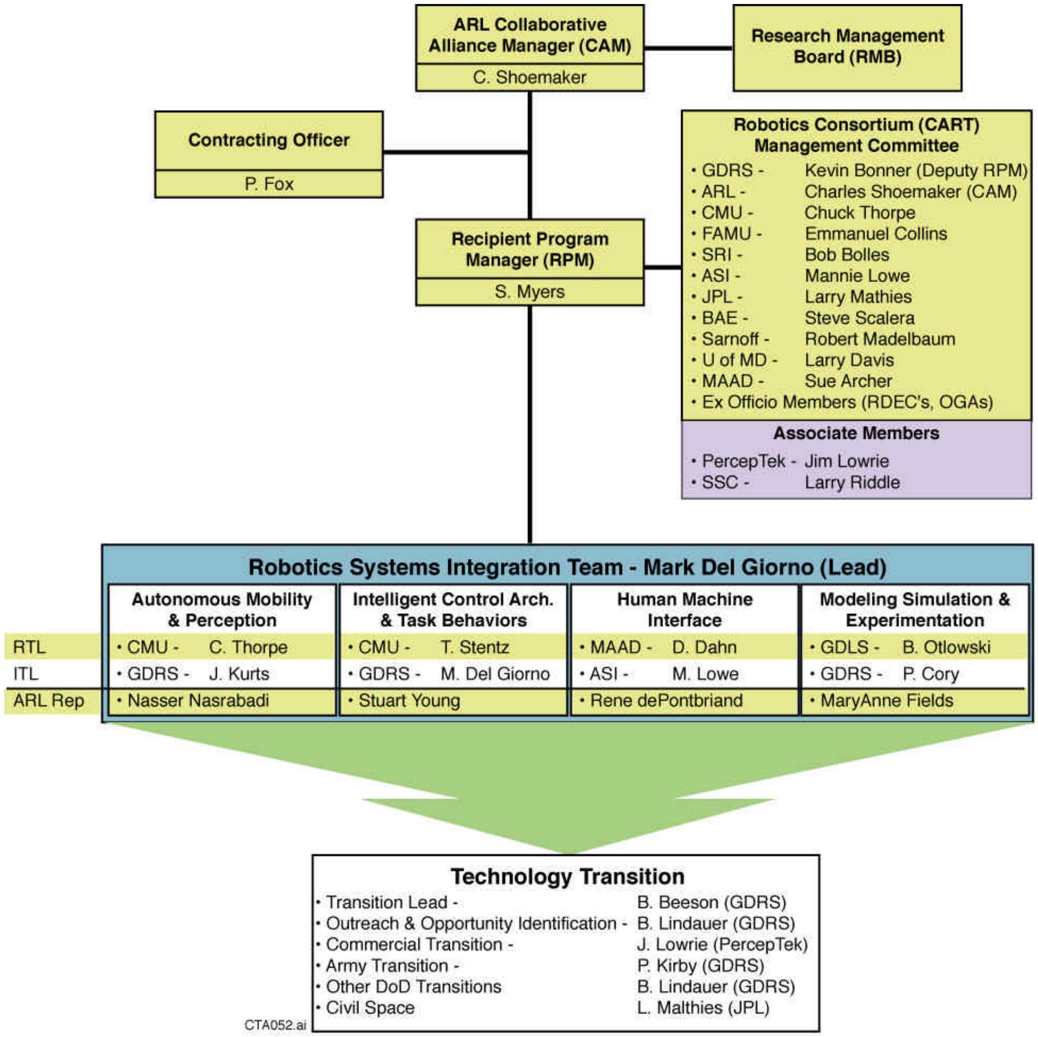
Robotics Consortium Members

The members of the Consortium are shown in the following table.

Industry Partners: General Dynamics Robotic Systems—the world leader in tactical robotics SRI International—a pioneer in the creation and application of innovative technologies Sarnoff Corporation—acknowledged world experts in fields from computer vision to MPEG compression Applied Systems Intelligence, Inc.—a software products and engineering services company specializing in knowledge based software products BAE Systems—world-class capabilities combine key in-depth skills in naval platforms, military aircraft, electronics, systems integration and other technologies Jet Propulsion Laboratory—managed by the California Institute of Technology, NASA's lead center for robotic exploration of the solar system. Micro Analysis & Design—providing expertise in computer simulation and modeling, human factors engineering and custom software development. Signal Systems—specializing in services and software products for communications and acoustic/radar systems through innovative signal processing and real time control solutions
Academic Partners: Carnegie Mellon University Robotics Institute—offering one of the world’s first doctoral degrees in robotics University of Maryland—hosts the majority of the CTA image research lab facilities Florida A&M—one of the oldest land-grant higher education institutions in Florida, FAMU offers a Ph.D. in engineering

Robotics Organization

General Dynamics Robotics Systems leads the Robotics CTA. The current members of the Consortium Management Committee (CMC) are outlined in the following organizational chart.



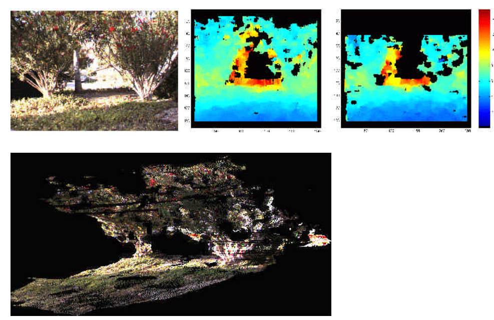
Robotics Research Highlights

Technical Area 1: Advanced Perception for Autonomous Mobility

Sensor Modalities

We made substantial advances in stereo vision and LADAR in recovering more accurate 3-D measurements from the sensors and in detecting obstacles and characterizing terrain in 3-D range data.

Stereo Vision



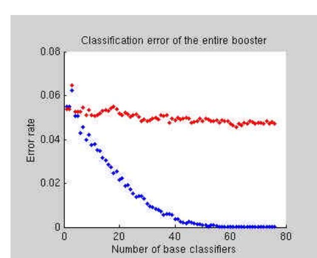
Complex Scene Reconstruction using Motion Stereo.

We increased the quality of stereo in very complex scenes by taking advantage of highly correlated scene information obtained through small motions of the sensor. This is particularly important in complex scenes with repetitive patterns that lead to mismatches or weak correlations (e.g., tall grass, leaves and branches), complete misses of thin objects (e.g., thin trees can be detected only at close range), etc. We recovered detailed 3-D data in complex scenes, such as complex forest scenes, where leaves and branches are intermingled and it is difficult to discern structures. The figure above shows an example of accurate stereo recovery in such a typical forested environment.

LADAR (Laser Radar)

We achieved crucial steps toward the development of the next generation of LADAR sensors for mobility. In particular, we modified the design to increase maximum range, to increase the ranging resolution, and to incorporate the ability to measure multiple returns from single pulses. The latter will be particularly important in terrain cluttered with vegetation in which LADAR returns include both returns from the terrain and returns from the obscuring vegetation. Additional development will include accurate time-tagging for synchronization with imaging sensors.

New Fusion Algorithm



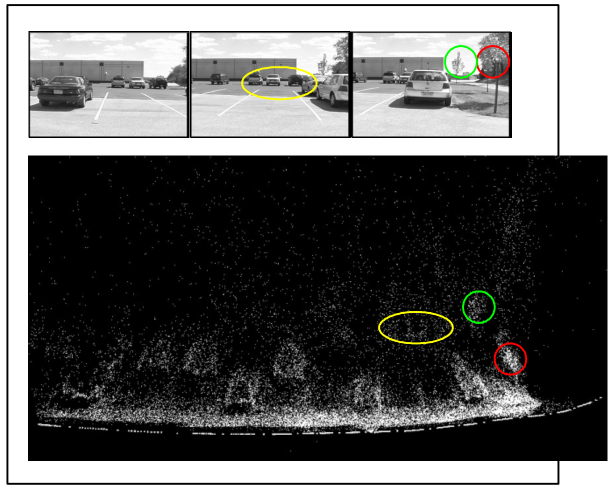
Decrease of the error rate by fusing classifier algorithms.

We developed a testbed for evaluating fusion and obstacle classification strategies that supports high-resolution stereo and LADAR, as well as color data, and implemented five obstacle classifiers and five fusion strategies.

We designed a statistical fusion approach in which, given a set of examples, the fusion algorithm refines iteratively the relative contributions of the different classifiers being fused. The resulting, combined classifier has better performance than any of the individual classifiers.

Complementary approaches applicable to different configurations of the vehicles and the missions—e.g., multiple vehicles vs. single vehicles or dense sequences of images vs. single snapshots from different positions of the vehicle were developed during FY02.

Mid-Range Scene Reconstruction



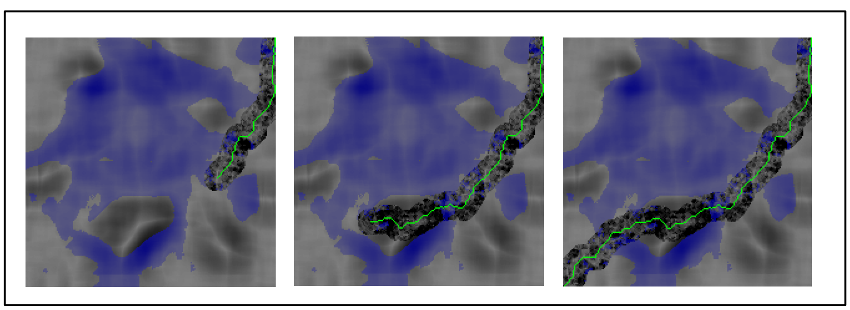
Mid-Range Scene Reconstruction.

Sarnoff developed a new technique to track features in a sequence of images, recover the relative positions and orientations of the cameras over the span of the sequence using the feature tracks, and recover the structure of the scene by triangulation using the feature tracks and the estimated camera geometry. The algorithm produces both a 3-D map of the environment and refined estimates of the vehicle poses over the course of the sequence. The current implementation includes a version of the robust pose and structure estimation algorithm that operates continuously on an incoming video stream and achieves a processing rate of approximately 10 frames per second running on a 1 GHz Pentium III PC. The software uses highly optimized implementations of key algorithms steps, together with an efficient data structure for representation of correspondences and 3-D points. This version of the algorithm has been tested on data from a test gantry as well as extended sequences captured from the XUV and is ready for transfer to the CTA vehicles.

Technical Area 2: Intelligent Control Architectures and Tactical Behaviors

Tactical Robot Behaviors

We developed a new dynamic re-planning algorithm called Constrained D* (CD*), which is able to optimize one metric, while satisfying a global constraint. It is able to re-plan in real time in response to unknown, uncertain, and changing environments. We combined CD* with our inter-visibility software to produce a software system capable of maximizing stealth (i.e., minimizing inter-visibility) while satisfying an arrival time constraint. CD* is one to two orders of magnitude faster than CA* for re-planning.

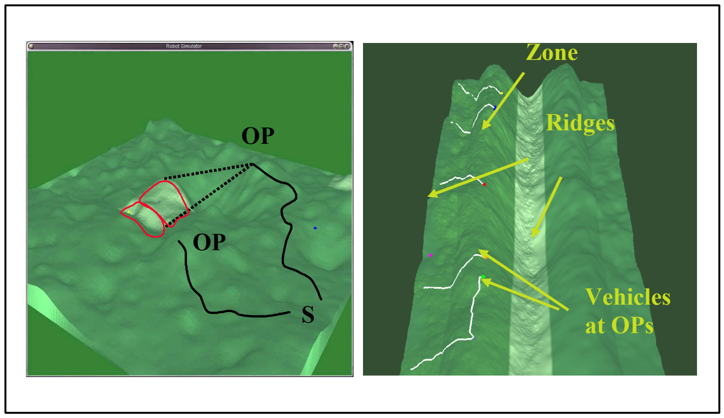


Constrained D Algorithm.*

Also, we developed an incremental inter-visibility engine for calculating line of sight between points on a terrain elevation map. This capability is important for determining stealth, sensor coverage, Reconnaissance, Surveillance, and Target Acquisition (RSTA), communications, perimeter formation, and other tactical operations. This package can update its calculations quickly, as new information is discovered, to support dynamic planning capabilities.

By discretizing viewing angles and pre-computing cells visible from each viewing angle, the engine can compute the areas visible to a source in a 1000 × 1000 map in one third of a second on a 1.8 GHz computer. The significance of this result is that the engine can quickly provide an updated visibility map to a route planner.

Multi-Vehicle Coordination



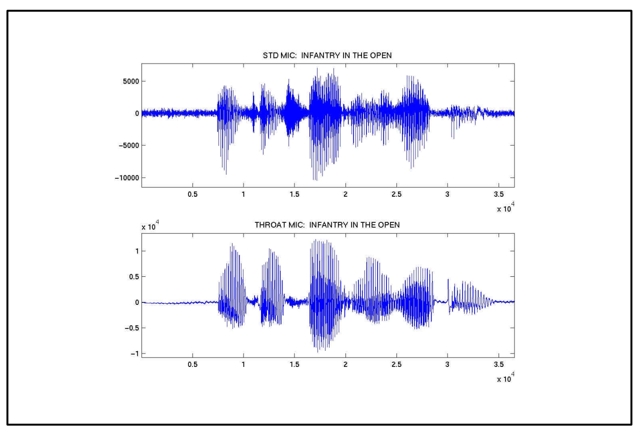
Multi-Vehicle Coordination.

We researched market-based techniques for coordinating multiple UGVs at the platoon and section level. In a market approach, peer agents (such as UGVs in a section) negotiate to exchange task assignments in order to maximize the mission benefit and minimize resource usage. A task pays revenue according to the benefit it provides to the mission, and costs are assessed based on resource usage. The agents attempt to maximize their own profits, but since profits are tied to successful mission completion, this self-interested approach results in best mission performance. The market techniques are robust to single point failures, take advantage of communication when available but are not dependent on it, gracefully handle loss of assets, can be reconfigured when the mission changes, and handle uncertainty in the terrain and battlefield conditions.

A new feature of the system allows the robots to discover new areas of interest (AIs) as they move toward their observation posts (Ops), and subsequently decompose these AIs into task trees to perform or to sell to other, more suitable, robots.

Technical Area 3: Human-Machine Interface

Spoken Language Interface



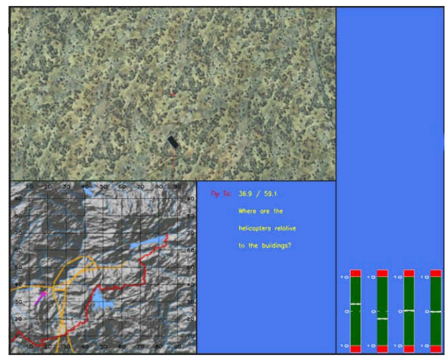
Soldier Machine Interface (SMI) Spoken Language Interface.

In this task, we developed interfaces for 1) an integrated crew station in a direct fire combat vehicle with robotic control requirements, 2) a separate single display control system to support scout missions, 3) dismounted control of unmanned ground vehicles. We addressed the human interactions and control mechanisms for the soldier-robot teams. Supervisory control, semi-autonomous direct control, and robotic teleoperation and remote control in multiple asset environments are characterized by high attentional human demand. Accordingly, research into multi-modal control systems and new display concepts are being investigated to help mitigate simultaneous demands imposed on the controllers.

We conducted testing and development of a focused spoken language interface (SLI) to allow robust speech recognition even in the noisy environment of military vehicles. A predefined grammar, based on the specifics of the OCU interface, was prepared and used for testing in a High Mobility, Multi-purpose Wheeled Vehicle (HMMWV). Signal to noise ratios were compared for both open air microphones and throat microphones. Specific examples of misinterpretation (such as "On" for "Off") and behavioral factors (such as speech modification during loud noise) were noted during an analysis of interpretation errors. The dialogue manager Ariadne was extended to provide support for SAPI compliant speech recognizers including the Microsoft speech engine and the manager was developed for use on multiple platforms, including Java, C++ and SQL, and the resultant system was implemented and tested on the SMI.

Workload Theory Development

In this task, we tested trust in automation, through experiments with pilots controlling one or two simulated unmanned air vehicles, with different missions and varying degrees of automation. Data analysis reveals substantial workload reductions by both auditory reallocation and automation offloading. In general the advantages to auditory offloading were borne more by the task whose modality was changed, rather than by concurrent tasks. The results also indicated that the task involving heavy cognitive involvement of image inspection did not benefit from auditory offloading.



Workload Theory Development.

Results of a review of the literature relating trust, workload, and imperfect automation were used in a presentation at the Trust in Automation workshop from ARL, which was performed as a cross-consortium effort between the Robotics and ADA CTAs in November of 2002.

Technical Area 4: Modeling, Simulation, and Experimentation

We assembled an integrated safeguarding system that includes external sensing; vehicle motion sensing; object detection and tracking; curb detection and tracking; vehicle path prediction; and collision prediction and warning. As part of this effort, CMU provided a vehicle testbed for data collection and algorithm refinement. The Navlab 11 testbed has been equipped with an enhanced IMU, two additional Sick sensors looking sideways, and reconfigured computing to provide real-time digitization of multiple video sources.

We investigated two existing Sarnoff algorithms for UAV data geo-registration in order to evaluate their applicability to the current problem:

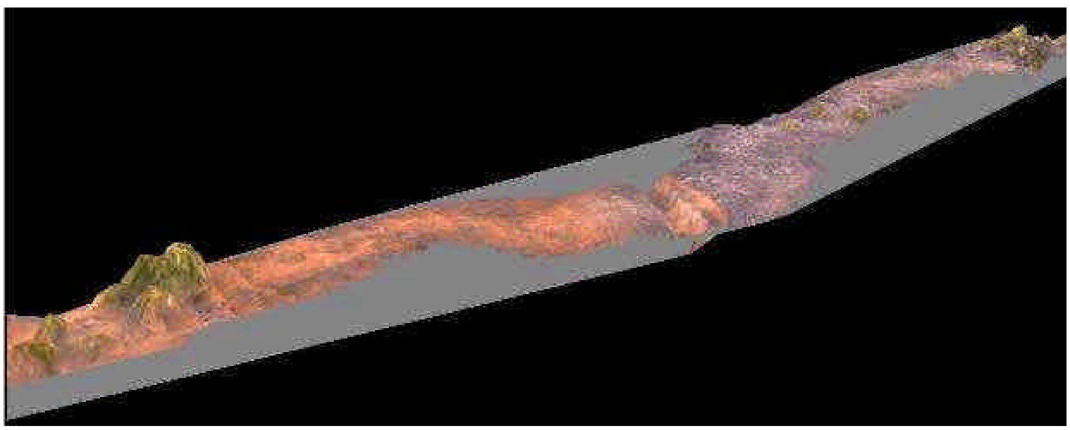
- An algorithm to align UAV imagery with satellite imagery and a corresponding DEM, and
- An algorithm to align UAV imagery of urban terrain with ground imagery of the same scene.

We performed identification of where these existing algorithms needed to be extended. In addition, new algorithms were devised for the cases where (a) satellite imagery and a DEM are unavailable, and (b) the setting is not urban, so that there are no flat surfaces (such as building faces) to lock onto, and (c) stereo data is available from the UAV.

The first figure shows a 2-D mosaic built from data from a low-flying UAV. The cross-hairs indicate where the ground vehicle was detected in the scene, as well as the orientation of the ground vehicle. While this 2-D mosaic provides useful information regarding the context of the UGV, it does not provide accurate 3-D locations of the obstacles in the scene relative to the UGV.

2-D Mosaic of Aerial Data.

In the next figure, however, a 3-D mosaic of the same scene is shown. This was created by using the 2-D mosaic to estimate UAV poses over time, and then mosaicing the stereo depth information based on these poses. In this 3-D mosaic, the various terrain features have effectively been aligned to the UGV's coordinate system.



3-D Mosaic of Aerial Data.

The new algorithm leverages current algorithms by replacing DEM information with stereo data obtained from the air, replacing satellite imagery with an overhead view from the UAV, performing visual tracking of the ground vehicle from the UAV to obtain relative pose information, and mapping UAV terrain information in the UGV coordinates.

Robotics Technology Transitions

The Army Semi-autonomous Robotics for Future Combat Systems (FCS) Science and Technology Objective (STO) and Robotic Follower Advanced Technology Demonstration (ATD) program are parallel efforts which provide powerful leveraging opportunities for CTA members.

The Robotics CTA is a primary technology development vehicle for both programs. CTA research in perception, intelligent control and behaviors, and man-machine interfaces, as well as modeling, simulation and experimentation in support of our key technical areas, will provide advanced autonomous mobility capabilities required for Army Objective Force Programs and other ground robotics efforts for the Joint Services.

General Dynamics Robotic Systems, the RCTA industrial leader, has entered into three task order contracts that utilize robotic technology:

- ***Basic Unexploded Ordnance Gathering System (BUGS)***—Task 1 is to finalize development and demonstration of operating scenarios for a team of cooperating mobile robots that reduces the risk to the Navy Explosive Ordnance Disposal (EOD) personnel during war-time clearance of multiple unexploded submunitions on the surface. As part of the behaviors developed, the system must autonomously navigate safely and reliably, identify Unexploded Ordnance (UXO), record their locations with a high degree of accuracy, and perform subsequent Blow-in-Place (BIP) and Pick Up and Carry Away (PUCA) functions. Supporting hardware and software solutions had to be capable of being manufactured in production quantities, within a reasonable timeframe, and at the target system cost.
- ***Common Robotic Kit***—Building on lessons learned from work on the ARL-supported Demo III XUV and BUGS, Task 2 is to develop and apply a Common Robotic Kit that would permit control of a Meerkat vehicle for use in development of Ground Standoff Mine Detection Systems for the Joint Program Office Unmanned Ground Vehicle Systems.
- ***UGV-ROP***—Task order 3 is to extend the application of the Common Robotic Kit design to develop the Unmanned Ground Vehicle Robotic Obscurant Platform (UGV-ROP) for the Joint Program Office Unmanned Ground Vehicle Systems.

Lessons learned from the CTA program are also being applied in the ***Vetronics Technology Integration*** robotic follower and Crew Automation Testbed (CAT) program at TARDEC.

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The Way Ahead

We are off to a good start with significant research accomplishments and transitions in 2002, supporting CERDEC, TARDEC, The Natick Soldier Center, INSCOM, and others. Technologies developed in the Alliance program will impact Future Combat Systems and the Objective Force, and we will continue to foster innovative research and collaborations that enable rapid transition. To further enhance the research multiplier that occurs when diverse researchers collaborate, cross-collaboration among Alliances is being emphasized and will be reflected in the Fiscal Year 2004 Annual Program Plans. Collaborative thrusts that are under consideration include projects in Robotics, Sensors, and Command and Control. ARL and all of our Alliance partners are committed to delivering timely, cutting edge technology that can be transitioned to the war-fighter. We will continue to deliver on that promise in the future.

John M. Miller

List of Acronyms

AESA	Active Electronically Scanned Arrays
AIs	Areas of Interest
AJ	Anti Jamming
AJCN	Adaptive Joint C4ISR Node
AODV	Ad-hoc On-demand Distance Vector (routing protocol)
AP	Advanced Perception
AQM	Active Queue Management
ARDEC	Armament R&D Center
ARL	Army Research Lab
ATD	Advanced Technology Demonstration
ATR	Automatic Target Recognition
BLOS	Beyond Line of Sight
BMP	Soviet Armored Personnel Carrier
BRDM	Soviet Armored Personnel Carrier
BUGS	Basic Unexploded Ordnance Gathering System
C^2	Command and Control
C^4	Command, Control, Communications and Computing
CA*	Constrained A
CAM	Collaborative Alliance Manager
CAT	Crew Automation Testbed
CD*	Constrained D – a new dynamic re-planning algorithm
CECOM	Communications and Electronics Command
CERDEC	Communication and Electronics Research, Development and Engineering Center
CIA	Central Intelligence Agency
CMC	Consortium Management Committee
CPOX	Catalytic Partial Oxidation
CPW	Coplanar Waveguide
CSEL	Cognitive Systems Engineering Laboratory
CTA	Collaborative Technology Alliance
DAP	Domain Announcement Protocol

List of Acronyms (cont'd)

DC	Direct Current
DCDP	Dynamic Configuration Distribution Protocol
DEM	Digital Elevation Map
DMFC	Direct Methanol Fuel Cell
DMR	Digital Modular Radio
DOA	Direction Of Arrival
DRIE	Deep Reactive Ion Etching
ECN	Explicit Congestion Notification
EO	Electro Optic
ESA	Electronically Scanned Antenna
FCS	Future Combat Systems
FFRDC	Federally Funded Research and Development Center
FH	Frequency Hop
FPA	Focal Plane Array
FRAGOs	Fragmentary Orders
HBCU	Historically Black College or University
HEMTT	Heavy Expanded Mobility Tactical Truck
HMI	Human Machine Interface
HMMWV	High Mobility Multipurpose Wheeled Vehicle
ICA	Intelligent Control Architecture
IMU	Inertial Measurement Unit
INSCOM	Intelligence and Security Command
INU	Inertial Navigation Unit
IP	Internet Protocol
IPAS	IP Autoconfiguration Suite
IUGs	Internetted Unattended Ground Sensors
LADAR	LAser Detection and Ranging
LADAR	Laser radar
LAIR	Laboratory for Artificial Intelligence Research

List of Acronyms (cont'd)

LCP	Liquid Crystal Polymer
LOS	Line of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LTO	Lead Industrial Organization
LWIR	Long Wave IR
MAC	Media Access Control
MAV	Micro Air Vehicle
MEA	Membrane Electrode Assembly
MEMS	Micro Electro Mechanical Systems
MEMS	Micro-electromechanical System
MIMO	Multi-Input Multi-Output
MIUGS	Micro Internetted Unattended Ground Sensor
MLD	Maximum Likelihood Detection
MLJD	Maximum Likelihood Joint Detection
MMIC	Monolithic Microwave Integrated Circuit
MMW	Millimeter Wave
MOSAIC	Multi-functional On-the-move Secure Adaptive Integrated Communications
MPEG	Moving Picture Experts Group
MR	Magnetic Resonance
MSE	Modeling, Simulation and Experimentation
MUSIC	MUltiple SIgnal Classification
MWIR	Mid Wave IR
NASA	National Aviation and Space Administration
NIMA	National Imagery and Mapping Agency
NIST	National Institute of Standards and Technology
NRL	Naval Research Labs
NRO	National Reconnaissance Organization
NVESD	Night Vision and Electronic Sensors Directorate
NVL	Night Vision Labs
OCU	Operator Control Unit

List of Acronyms (cont'd)

OFDM	Orthogonal Frequency-Division Multiplexing
OFW	Objective Force Warrior
ONR	Office of Naval Research
OP	Observation Point
OSPF	Open Shortest Path First (routing protocol)
PACOM	Pacific Command
PEM	Proton Exchange Membrane
PN	Pseudorandom Noise
QWIP	Quantum Well Infrared Photoconductor
RCTA	Robotics Collaborative Technology Alliance
RDEC	Research, Development and Engineering Center
RHFC	Reformed Hydrogen Fuel Cell
RIE	Reactive Ion Etching
RMB	Research Management Board
RSTA	Reconnaissance, Surveillance, and
SA	Situation Awareness
SAPI	Small Arms Protective Insert
SAPI	Speech Application Programming Interface
SASO	Stability and Support Operations
SBCCOM	Soldier and Biological Chemical Command
SCTP	Stream Control Transmission Protocol
SFR-CACC	Split Fast Retransmit Changeover-Aware Congestion Control
SiC	Silicon Carbide
SLI	Spoken Language Interface
SMI	Soldier-Machine Interface
SNS	Specialized Network of Sensors
SOFC	Solid Oxide Fuel Cell
STRICOM	Simulation, Training, and Instrumentation Command
TA	Target Acquisition
TACOM	Tank Automotive Command
TAL	Technical Area Lead
TARDEC	Tank Automotive Research, Development and Engineering Center

List of Acronyms (cont'd)

TCP	Transmission Control Protocol
UAV	Unmanned Air Vehicle
UAVs	Unmanned Air Vehicles
UGV-ROP	Unmanned Ground Vehicle Robotic Obscurant Platform
UGVs	Unmanned Ground Vehicles
UWB	Ultra-Wideband
XUV	Experimental Unmanned Vehicle